“*क्राईसेंथमम मोरीफोलियम* रमात. में दीप्तिकालिक अनुक्रिया पर अध्ययन”

“Studies on Photoperiodic Response in *Chrysanthemum morifolium* Ramat.”

SURENDRA SINGH CHAUHAN

DIVISION OF FLORICULTURE AND LANDSCAPING

ICAR-INDIAN AGRICULTURAL RESEARCH INSTITUTE

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“Studies on Photoperiodic Response in *Chrysanthemum morifolium* Ramat.”

By

Surendra Singh Chauhan

A thesis
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Approved by:

Chairman	:	**Dr. Mam Chand Singh**	________________
Co-chairman	:	**Dr. Kanwar Pal Singh**	________________
Members	:	**Dr. Gunjeet Kumar**	________________
		Dr. C. Bharadwaj	________________
		Dr. D. K. Sharma	________________

Division of Floriculture and Landscaping
ICAR-Indian Agricultural Research Institute
New Delhi-110012, India

Dr. Mam Chand Singh
Principal Scientist

CERTIFICATE

This is to certify that the thesis entitled **"Studies on Photoperiodic Response in *Chrysanthemum morifolium* Ramat."** submitted to the Faculty of the Post Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirement for the degree of **Master of Science in HORTICULTURE**, embodies the results of bonafide research work carried out by **Mr. Surendra Singh Chauhan** under my guidance and supervision, and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help availed during the course of investigation as well as source of information have been duly acknowledged.

Date: 24.06.2017 **(Dr. Mam Chand Singh)**

Date: New Delhi Chairman, Advisory committee

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Dedicated to

My Family

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ABBREVIATIONS

^0C	Degree Celsius
%	Percentage
ANOVA	Analysis of variance
CBRB	Completely randomized block design
CD	Critical difference
CGR	Crop growth rate
cm	centimetre
cvs.	Cultivars
DIF	Diurnal temperature alternations
DLI	Daily light integral
EOD- FR	End of day Far-red
et al.	And others
Fig.	Figure
FL	Fluorescent lamps
g	gram
HPS	High pressure sodium
INC	Incandescent
LAI	Leaf area index
LD	Long day
LEDs	Light emitting diode
LMA	Leaf mass per unit leaf area
mg	milligram
mm	millimetre
NAR	Net assimilation rate
No.	Number
PFD	Photon flux thickness
PPF	Photosynthetic photon flux
RGR	Relative growth rate
RH	Relative Humidity
PAR	Photo-synthetically active radiation
SD	Short day
SE (m)	Standard error of mean deviation

Chapter 1

INTRODUCTION

Owing to an enormous increase in demand for variety of flowers and products, floriculture has become one of the important area and comprised of different floricultural products i.e. cut flowers, pot plants, cut foliage, seeds, bulbs, tubers, rooted cuttings and dried flowers or leaves. In India, during 1993-94 the area was 53 thousand ha produced 233 thousand MT loose flowers and 555 million number cut flowers. But now, about 309 thousand ha area was reported under cultivation in floriculture in 2^{nd} advance estimate of 2016-17 with a production of 1653 thousand MT of loose flowers and 593 thousand MT of cut flowers (NHB, 2017).

Chrysanthemum is an auspiciously the first flower in the winter season and referred as one of the oldest cultivated flowers. Most of the present *Chrysanthemum morifolium* Ramat. are complex hybrids of many species which are native to China and Japan. *Chrysanthemum* belongs to the family *Asteraceae* (former *Compositae)* and its inflorescences are known as capitulum. It is an important greenhouse flower crop throughout India and worldwide, used as a cut flower and pot plant. It is also grown in open field as well as under protected conditions for cut and loose flowers. There are vast range of chrysanthemum varieties differing in colour, form, size, reaction time, etc. (Trip *et al.,* 2000). However, a few varieties of cut chrysanthemum for year round flower production (Van der Hoeven, 1987).

In India, Himachal Pradesh rank first in cut chrysanthemum production and Andhra Pradesh for production of in loose chrysanthemum flowers. Chrysanthemum is known to have strong sensitivity to the ambient temperature and day length, being short day plant for flowering. For flower bud initiation, continuous minimum dark period of 9-9.5 h is necessary (Post, 1948). Light is an essential component in the production of chlorophyll and in the process of photosynthesis, by which plants manufacture food in the form of sugar (carbohydrate). Subsequently has an influence on growth and flower induction due to the internal responses like movement, phototropism, photo-morphogenesis, translocation, mineral absorption and abscission as shown and provided in the various studies conducted by several researchers. A slight change in climatic factors influences the plant growth processes such as photosynthesis, respiration, transpiration, breaking of dormancy, germination, protein synthesis and translocation. A small change in light and temperature regimes may affect the translocation of photosynthate, faster at higher levels resulting plants, tend to mature earlier. All forms and types of chrysanthemum are categorized as a short day plant where it develops flower buds at a day length less than 13.5 h therefore the blooming period is short under traditional cultural method, as apparently reported under North-Indian conditions.

Commercial production needs a controlled flowering for year round availability of cut flowers. The flowering and reaction time for flower induction in chrysanthemum in relation to temperature and light has been studied extensively. Chrysanthemum is adapted to grow faster under natural long day irradiance and tends to accumulate greater dry weights in leaves, stems, roots as well as increased leaf area under the high irradiance treatments (Gislerod and Nelson, 1997). Internodal elongation is influenced and increased by the quantity and quality of light under red and far red light (Calthy, 1974). At higher light intensities, plants generally flower earlier (Karlsson *et al*., 1989) and total flower dry mass increases, mainly by increasing the flower number rather than the mass of individual flowers (Carvalho and Heuvelink, 2003). However at higher temperatures, a larger number of flowers and leaves on the main stem have been reported (Karlsson *et al*., 1989), but the diameters of individual flowers are generally smaller (Carvalho *et al*., 2005). Both, time to flowering and time to visible flower bud appearance showed an optimum response to temperature between 17°C and 22°C (Adams *et al*., 1998) and it is found that flowering response is three time more influenced by night temperature than day temperature (Calthy,1955).

Basically, growth is derived from light interception; rules are defined to partition incremental growth over differential components (e.g. leaves, stems, roots), taking into account the factors and processes which affect the growth rate (e.g. temperature, nutrients, water, and ambient CO_2 concentration) as shown by different research experiments in chrysanthemum (Van Ittersum *et al*., 2003). Light use efficiency have shown rather flat temperature optimum, which is dependent on the light level (Van der Ploeg and Heuvelink, 2006) and effects the final growth and flowering. Light quality has been reported affecting the growth and morphology in different light sensitive plants. Light affect total leaf area production, in long day condition total leaf production increases and longer and broader leaves growth obtained under long day condition (Cockshull, 1976). Increase in fresh weight, leaf area and chlorophyll content were observed highest when exposed to a mixture of red and blue light (RB) and a fluorescent lamp (FL). In contrast, growth was severely inhibited under the mixture of blue and far red light (BFr). However, light did not affect the number of nodes but internodal length greatly; highest stem length could be observed under red and BFr. Leaf stomata has greatest growth, smallest in number and however, biggest size under RB and lowest growth, largest number and smallest size in BFr (Kim *et al*., 2004).

Year round production of quality chrysanthemum is a constant challenge to the problem for the growers, as the seasonal variations in daily light integral will produce large seasonal fluctuations in yield and quality. Under North-Indian conditions chrysanthemum does not produce sufficient stem length due to natural short day. Therefore, quality of cut flower goes down and the farmers not get good prices in both domestic as well as in export market. Besides this an erratic supply tends to develop an unregulated market. The factors like photoperiod, temperature, relative humidity, light intensity and CO_2 concentration are deciding in the production process of cut chrysanthemum under greenhouse/ polyhouse keeping an optimal condition over these factors, grower can take up to five crops in a year, from the same area. Under controlled condition desired stem length can be achieved by exposing the crop at earlier stages to an artificial light providing extended day length. Mostly, HPS bulbs are used to illuminate the crop to achieve an efficient delay and quality flowers, use of LEDs lighting is becoming popular for maximising photosynthetic efficiency of the plants. However, LEDs are more secure to work than current lights since they don't have glass envelopes or high touch temperatures, and they don't contain mercury. LEDs lighting has to be fully integrated and optimized within the greenhouse system in order to reach a sustainable and economically viable production. It has been demonstrated that LEDs can bring a revolution in protected horticulture to obtain the higher plant produce with superior quality (Morrow, 2008), especially in a crop like, chrysanthemum where photoperiodic crop regulation is achieved successfully to reduce the crop cycle with quality production.

The experiments conducted on photoperiod in chrysanthemum have shown that under available natural low irradiance, decrease day length there is an early flower induction even without attaining sufficient stem length (Kumar and Singh, 2017). However, supplementing the day length with PAR (Photo-synthetically active radiation) through smart LEDs has been successfully used to increase the day length without disturbing the dark period required for bud induction achieving elongated stems. An admixture of 80%Red + 20%Blue LEDs in terms of PAR has led to faster growth and an early flower induction by fixing more unit of dry weight due to an exposure to blue LEDs and highest accumulation of light for an efficient photosynthesis (Singh *et al.,* 2013).

Chrysanthemum does not flower normally when exposure to the longer photoperiods. Shorter day length tends to induce flower without being vegetative elongation. Therefore, using PAR through smart LEDs, there is a possibly to produce desired stem length and induction of quality flowers in short production cycle even under long days. Using of LEDs, the chrysanthemum cut flowers can be produced round the year especially in off season to meet out the demand of flowers in domestic and export market. It is therefore, confirmed that there is a need to study the pattern of virtual growth in light sensitive chrysanthemum so as to develop a research model for achieving productivity, and flower quality in varieties, Thai Chen Queen and Zembla (both Standard) are being considered for this study with the following objectives.

OBJECTIVES:

1. To study the effect of photoperiod on vegetative growth in chrysanthemum using different coloured LEDs.
2. To study the response of different coloured LEDs on induction and quality of flowers in chrysanthemum.

Chapter 2

REVIEW OF LITERATURE

Chrysanthemum is an important greenhouse crop being grown in India and worldwide, it is second most grown cut flower in the Netherlands, next to rose (Spaargaren *et al.,* 2002). Quality cut chrysanthemum could be grown year round through modification in photoperiod under greenhouse with sufficient stem length (Kurilcik *et al.,* 2008). An immense breeding work done in chrysanthemum has resulted in release of a number of varieties where some varieties are photo insensitive for flowering but when they are grown under less light duration they could not produce sufficient stem length (Van der Hoeven, 1987).

Vince-Prue (1975) reported that when night lengths are short, flowering can be delayed or prevented in chrysanthemum plants by providing day light extension or interruption in night by lighting. Various electric lamps are used for night interruption lighting to prevent or delay flowering which is reported to enhance vegetative growth and quality flowers in short day plants. High pressure sodium (HPS) lamp, fluorescent light, metal halide lamps, incandescent (INC) light and low-pressure sodium lamps are commonly used in greenhouse for artificial lighting. Light quality has been reported to affect the growth and morphology in different light sensitive plants. Light affect total leaf area production and long days promote longer and broader leaves (Cockshull, 1976).

Under continuous white light (WL), growth of the primary internode in *Sinapis alba* L. was reported extended by low red (R): far-red (FR) ratios achieving the longer stem as well as the larger leaves. Conversely, the growth advancement by end-of-day light treatments was only activated by FR, perceived by the leaves and cotyledons, while FR given to the growing internode alone was absolutely ineffectual. Continuous WL and FR combined given to the internode were likewise in effective if whatever is left of the shoot remained in darkness. The increase by WL of the growth-stimulatory impact of low phytochrome photoequilibria in the internode appears to be intervened by a specific blue light absorbing photoreceptor, as blue deficient light promoted background stem growth comparatively to WL however did not amplify the response to the R: FR ratio in the internode. Supplementing the blue-deficient light with low fluency rates of blue restored the primitive impact of low R: FR reaching the internode (Casal and Smith, 1988).

It has been reported by Barta *et al.* (1992) in the photo-synthetically active radiation (PAR) range, the electrical efficiency of gallium aluminium arsenide red LEDs has been reported to be greater than efficiency of the fluorescent lamps and resemble to the high pressure sodium (HPS) lamps. In watermelon plants, the growth controlling capacity of photomorphogenic light (EOD R and FR) was influenced by predominant direction of exposure , wherein an irradiation of the abaxial surface of leaf with fiber-optic transmitted EOD FR enhanced elongation of internode by 88% as compared with controls (Graham *et al.,* 1997). Chrysanthemum is a qualitative short day plant which flower uniformly when critical day-length is 13.5 h or less, but it fails to flower under the longer critical photoperiods (McMahon, 1999). Erwin and Warner (2000) worked in potted plants and reported that in many plant species flower induction is synchronized temporally during the year by photoperiod. Many commercial potted plant growers have used manipulation of photoperiod to induce flowering in short-day plants on a year round basis. Basically, growth is derived from light interception; rules are defined to partition incremental growth over differential components (e.g. leaves, stems, roots), taking into account the factors and processes which affect the growth rate (e.g. temperature, nutrients, water, and ambient CO2 concentration) as shown by different research experiments in chrysanthemum (Van Ittersum *et al*., 2003).

Runkle and Fisher (2004) mentioned that in photo-sensitive plants, flowering is regulated by duration of light i.e. photoperiod. In these crops during greenhouse production, photoperiod can be artificially extended or reduced to induce flowering or to maintain vegetative growth. It may help the growers to efficiently schedule crops to flower for predetermined market demand by manipulating the photoperiod. In chrysanthemum, to promote flowering when natural night lengths are long, the photoperiod must be reduced by extending black material over the crop or providing dark environment.

Clifford *et al.* (2004) reported that the most commercial market growers require poinsettia (*Euphorbia pulcherrima* Willd.) to produce plants within strict height specifications. For reduction of plant height through limiting internodal extension plant growth retarding chemicals are commonly used, but in some advanced countries, growers are being pressurized to reduce the use of chemicals. Recently, a photo-selective film was developed that specifically reduces the transmission of far-red light [(FR), 700 to 800 nm], offering an alternative technique for height control. Out of two complementary trials on poinsettia conducted in United Kingdom and United States of America, an approximately 20% height reduction were obtained in plants grown under the FR film for 10 to 12 weeks than control plants growing under neutral density films transmitting a similar photosynthetic photon flux as the FR film. The FR filter delayed time to 50% bract colour and first visible cyathia by 6.0 and 3.5 days, respectively, but did not affect the time to final harvest. In the trial taken up in United States of America, an average of 25% more axillary branches were produced under the FR film than those under the control with neutral density film. In addition, the effect of reduced red (R) wavelength, 600 to 700 nm and blue (B) wavelength, 400 to 500 nm light on internode length, plant biomass, and axillary branching were also determined using other photo-selective plastics. Compared with plants under the control with neutral density film, internode length was 9% or 71% greater in plants grown under environments deficient in B or R, respectively. This indicates that poinsettia is highly sensitive to the R: FR ratio and that spectral manipulation have potential for height control in commercial poinsettia crop.

Faust *et al.* (2005) stated that daily light integral (DLI) is the rate at which PAR is delivered over a 24-hour period and is a useful measurement for describing the greenhouse light environment. Eight bedding plant species *Ageratum houstonianum* L., *Begonia ×semperflorens-cultorum* L., *Impatiens wallerana* L., *Tagetes erecta* L., *Petunia ×hybrida* Juss., *Salvia coccinea* L., *Catharanthus roseus* L., and *Zinnia elegans* L. Were grown in direct solar radiation (in outdoor) or under one of three shade cloths (50, 70 or 90% photosynthetic photon flux (PPF) reduction) that provided DLI treatments ranging from 5 to 43 mol m^{-2} d^{-1}. As DLI increased from 5 to 43 mol m^{-2} d^{-1} total plant dry mass increased for all species, except impatiens and begonia. Total plant dry mass of impatiens and begonias increased as DLI increased from 5 to 19 mol m^{-2} d^{-1}. Impatiens, begonia, salvia, ageratum, petunia, vinca, zinnia, and marigold attained 50% of their maximum flower dry mass at 7, 8, 12, 14, 19, 20, 22, and 23 mol m^{-2} d^{-1}, respectively. The highest flower number for salvia, petunia, vinca, and zinnia occurred at 43 mol m^{-2} d^{-1}. Time taken for flowering decreased for all species, except impatiens and begonia as DLI increased to 19 or 43 mol m^{-2} d^{-1}. There was no sequential plant height in response to DLI across species, although the shoot and flower dry mass per unit height increased for all species as DLI increased from 5 to 43 mol m^{-2} d^{-1}.

Supplemental lighting is used in Northern countries from winter to spring, to obtain quality and all year round production of cut flower and pot plants. Manipulation of the light spectrum through lamps is very effective for triggering potential benefits for the plants (Brazaityte *et al.,* 2006). Van der Ploeg and Heuvelink (2006) reported that light use efficiency have shown rather flat temperature optimum, which is dependent on the light level and effects the final growth and flowering.

Hogewoning *et al.* (2010) found that in cucumber grown under monochromatic blue light has been associated with leaf characteristics which also develop under high irradiances and blue light dose response curves were made for the photosynthetic properties. Only the leaves developed under monochromatic red light displayed dysfunctional photosynthetic operation, characterized by a suboptimal and heterogeneously distributed dark-adapted F_v/F_m, a stomatal conductance unresponsive to irradiance, and a relatively low light-limited quantum yield for CO_2 fixation. Only 7% blue light was sufficient to prevent any overt dysfunctional photosynthesis, which can be considered a qualitatively blue light effect. The photosynthetic capacity (A_{max}) was twice as high for leaves grown at 7% blue compared with 0% blue, and continued to increase with increasing blue percentage during growth measured up to 50% blue. At 100% blue, A_{max} was lower but photosynthetic functioning was normal. The increase in A_{max} with blue percentage (0–50%) was associated with an increase in leaf mass per unit leaf area (LMA), nitrogen content per area, chlorophyll content per area, and stomatal conductance. Above 15% blue, the parameters A_{max}, LMA, chlorophyll content, photosynthetic nitrogen use efficiency, and the ratio of chlorophyll and nitrogen had a comparable relationship as reported for leaf responses to irradiance intensity.

Folta and Childers (2008) reported that for plant cultivation, light is a critical yet passive entity. The potential to actively implement dynamic lighting strategies to control plant growth and development holds great promise in the future of plant cultivation. Light has a potential to work as a growth regulator. LEDs technology is well suited for the application, because light quality, quantity, photoperiod, and combinations these can be controlled with great precision. Specific light combinations may be adjusted throughout the life of a plant to potentially optimize traits of interest such as maintenance of vegetative growth, synchronization of flowering, plant height control, or acceleration of juvenility.

Lights have the wavelength of 350 to 750 nm, such wide range of light spectrum appears to be low quality and unnecessary for promoting plant growth and development and also consume more electrical power in tissue culture laboratory. These lights generate heat, thus it is need of an efficient light source to improve production and quality and reduction of cost in tissue culture laboratory (Yeh and Chung, 2009). In *Alternanthera brasiliana* Kuntze plants gown under *in-vitro*, growth parameters including specific leaf mass, thickness, and leaf density were lowest in plants grown under red light. Blue light induced the largest number of leaves per plant, and the largest thickness and area of the leaf blade. Green and red lights induced the smallest leaf areas. The thickness of the abaxial face epidermis and spongy parenchyma of the plants was significantly diminished in plants drown under red light. The thickness of the palisade parenchyma and upper epidermis were altogether expanded in plants grown under blue light, contrasted with the other fluorescent light treatments. The specific spectral band also impacted the differentiation of mesophyll cells. The dark and under red light, the mesophyll was homogenous; and in the dark and under green light, the leaves were more compact. Under blue light, the cells showed the characteristic palisade morphology. It suggests that *Alternanthera* can be achieved by culturing the plants *in-vitro* under a mix of blue and red light (Macedo *et al.,* 2011).

In rapeseed (*Brassica napus* L.) cultivar 'Westar plantlets' gown under *in-vitro* it is found that the proliferation rate was greater in plantlets that were cultured under B light than those under fluorescent lamps (FL). The differentiation rate, fresh weight, dry weight, soluble sugar concentration and stem diameter were greater in plantlets that were cultured under B: R = 3:1 light than under FL. The B: R = 3:1 LED light was appropriate for rapeseed plantlet growth *in-vitro* and can be used as a priority light source in the rapeseed culture system as per its differentiation rate, proliferation rate, growth rate, and transplantation survival rate (Li *et al.*, 2013).

Van Ieperen and Trouwborst (2007) suggested that the application of LEDs as potential source for assimilation lighting in protected cultivation systems opens up a range of new possibilities. LEDs provide light in a range of very narrow wavelength and directly do not emit heat radiation. A little amount of heat is produced by LEDs due to their limited energy conversion efficiency can be drawn away via convective cooling. LEDs can be applied at relative dark places within the crop to increase leaf photosynthesis at locations where assimilation light normally does not penetrate. Theoretically, this type of intercrop lighting could significantly increase crop photosynthesis. Existing simulation models for protected cultivation systems can be used to simulate the potential effects this intercrop lighting on crop photosynthesis.

Massa *et al.* (2008) reported that LEDs have tremendous potential as supplemental or sole source lighting systems for crop production both on and off earth. Their small size, wavelength specificity, long operating lifetime, durability, relatively cool emitting surfaces, and linear photon output with electrical input current make this solid-state light source which is ideal for use in plant lighting designs. Because the output waveband of LEDs (monochromatic, non phosphor-coated) is much narrower than that of traditional sources of electric lighting used for plant growth, one challenge in designing an optimum plant lighting system is to determine wavelengths essential for specific crops. Work at NASA's Kennedy Space Centre has focused on the proportion of blue light required for normal plant growth as well as the optimum wavelength of red and the red/far-red ratio. The addition of green wavelengths for improved plant growth as well as for visual monitoring of plant status has been addressed. Like with other light sources, spectral quality of LEDs can have dramatic effects on crop anatomy and morphology as well as nutrient uptake and pathogen development Potential LED benefits to the controlled environment agriculture industry are numerous and more work needs to be done to position horticulture at the forefront of this promising technology.

Morrow (2008) stated that the LED lighting frameworks have over existing plant lighting, including the capacity to control spectral composition, the capacity to create high light levels with low brilliant warmth yield when cooled appropriately, and the capacity to keep up valuable light yield for quite a long time without substitution. They are strong state gadgets, so LEDs are effectively coordinated into computerized control frameworks, encouraging extraordinary lighting projects, for example, “daily light integral’’ lighting and dawn and nightfall re-enactments. LEDs are more secure to work than current lights since they don't have glass envelopes or high touch temperatures, and they don't contain mercury. They have the potential of passing significant savings to greenhouse growers. LEDs lighting has to be fully integrated and optimized within the greenhouse system in order to reach a sustainable and economically viable production. The LED lighting has yet to be fully integrated within the greenhouse control system and should be optimized in terms of light output, while LEDs luminaries cost should be reduced in order to reach a sustainable and economically viable production. This new lighting technique i.e. LEDs can bring a revolution in protected horticulture to obtain the higher plant produce with superior quality.

Therefore, for fulfilling the aim of the study, a relevant literature is collected as possible for helping the study to investigate the effect of different coloured LEDs in the vegetative growth and flowering by providing photo synthetically active radiation (PAR) from different coloured (W, B, R, 80%R + 20%B) LEDs maintained at 15 h photoperiod along with control i.e. 11 h under normal light and 110 ± 5 μmol m^{-2} s^{-1} irradiance on chrysanthemum potted plants under controlled condition.

2.1 Photo-morphogenesis in plants

Quality of light spectrum has great effects on the plant growth, development, and physiology (Smith, 1982). Barnes and Bugbee (1991) reported that both red and blue light are effective to inducing photo-morphogenic responses in plants. Red, far red and blue region of the spectrum play the critical importance for the growth, development and morphology of the plants (Wheeler *et al.,* 1991). Higher plants transform solar energy into chemical energy and use light as an informational indication to control the physiological responses through the process of photosynthesis during their whole life cycle; these responses are called as photo-morphogenesis (Kendrick and Kronenberg, 1994). The use of red LEDs was initially accepted since the red wavelengths (600–700 nm) are efficiently absorbed by plant pigments, such as chlorophyll, which has one of the absorption peaks at 665 nm and current commercial lamps are usually based on a 80% red and 20% blue light combination (Sager and McFarlane, 1997).

Plants which receive more sunlight have the higher photosynthetic rate. Photoperiod refers to the duration of time that a plant exposed to the sunlight. Quality of light mentioned by the wavelength which received by the plants. Plant growth, development and flowering are controlled by the manipulating light duration and quality of artificial lighting (Heo *et al.,* 2003). Rankle and Heins (2005) reported that light intensity and quality of light has direct effect on plants from seed germination to flowering. The flowering process is a complex phenomenon; a variety of environmental factors influences the flowering process of plants, particularly light and temperature. Singh *et al.* (2013) reported that chrysanthemum plant is sensitive to both photoperiod and temperature exhibiting a strong diurnal response even under long days. It is a regulatory effect of photoperiod on the growth, development and differentiation of plant in which it turns from vegetative to reproductive phase.

2.2 Photoreceptors and their role

Flint (1934) was the first, who reported that lettuce seed germination is promoted by red light and germination was inhibited by far red light. Light signal perceived in the plants may determine the bud induction process in space and time as inherent genetic information. It describes the perceptibility of the light signals by the phytochromes and other photoreceptors. There are three classes of photoreceptors- phytochromes, cryptochromes and phototropin and have been characterized by their molecular details and functions. In which, each group of photoreceptors work both independently and in combination with the others to regulate plant growth and development. The eco-physiological functions of the phytochromes are determined by their photo-sensory indication, which in turn depend on photochemistry. The mottled characteristic of the phytochromes is reversible photochromism, the property of changing colour changing property on absorption of photon and of returning to the original form on the another photon absorption. The maximum absorption of the phytochrome 'Pr' form is close to the red light, but the 'Pfr' form absorbs at the far-red light. This means that the phytochromes may be used as sensitive estimators of the spectral changes within plant communities when photoperiod interacts with photosynthetic structures (Smith, 1982).

Cryptochromes are flavin containing blue light photoreceptors, they are initially found in plants. First cryptochrome gene was isolated through the insertional cloning of an *Arabidopsis thaliana* mutant allelic to hy4 (Ahmad and Cashmore, 1993). Phytochrome pigments are sued by plants to sense the photoperiod (Fosket, 1994). Daylight contains equal proportions of red (R) and far red (FR) light but within plants that ratio is deceased by the absorption of red light by photosynthetic pigments. Changes in the red: far red light ratio is more reliable indicators of the proximity of potentially competing neighbours than the concomitant reductions in the total amount of light penetrating the canopy. Inside dense canopies, the far red radiation scattered or reflected from leaves is a unique and unambiguous signal of the nearness of neighbours (Ballare *et al.,* 1987) and hence of community density (Gilbert *et al.,* 1995).

Phytochromes are red and far-red light-sensitive but cryptochromes and phototrophins absorb blue (B) light (Runkle and Heins, 2001). Mockler *et al.* (2003) mentioned that photoreceptor viz. phytochrome (far red light receptor) and cryptochrome (blue light receptor) regulates the flowering in plants. Arabidopsis grown under short day condition, the protein abundance of phytochrome A and cryptochrome 2 shown in plants diurnally rhythm and proportion of these two photoreceptor are day length sensor. Arabidopsis contains at least three cryptochromes, cryptochrome 1 (cry1) and cryptochrome 2 (cry2) localized predominantly in the nucleus and the cytoplasm and one cryptochrome 3 (cry3) in the organelles (Kleine *et al*., 2003). Phytochromes and cryptochromes inhibit hypocotyls elongation, promote cotyledon expansion, and initiate chloroplast development and initiate leaf growth for controlling the seedling establishment phase to start photosynthetic life of seedlings (Chen *et al.,* 2004).

Takemiya *et al*. (2005) studied that plants primarily use light for energy source but light also play a signal for flowering direction. Plants sense light quality *via* photoreceptors categorized viz. phytochromes, cryptochromes and phototropins, and these photoreceptors are in charge of a wide spectrum of morphogenesis. Phototropins optimize the photosynthetic performance even under low PAR in natural environment, so their use is now possible for promotion of plant growth. Mathews (2006*)* reported that phyA allows seedling establishment under dense plant canopy and thus it has a competitive advantage for flowering plants that possess phyA. Folta and Maruhnich (2007) reported that light profoundly affects plant growth and development. Red and blue light are the best for photosynthetic metabolism in plants. It is therefore, no surprise that these light qualities are particularly especially productive in the developmental attributes associated with autotrophic growth habits. Photo-synthetically inefficient light qualities also impart important environmental information to a developing plant, viz. Far-red light reverses the effect of phytochromes, leading to changes in gene expression, plant architecture, and reproductive responses. Recent evidence shows that green light also has discrete effects on plant biology, and the mechanisms that sense this light quality are now being elucidated. Green light has been shown to affect plant processes via cryptochrome dependent and cryptochromeindependent means. The effects of green light oppose those directed by red and blue spectrum.

2.3 Role of Photoperiod in vegetative growth

Electric light was introduced in the middle of 19^{th} century to regulate the growth and development of plants. Mangon (1861) did the first attempt to study the effect of electric light to plant. He provided light from carbon lamp, these lamp are not in practical use due to their short lifetime. Thomas Edison started his research in 1878 to develop an incandescent lamp and after its development production and availability of this lamp increased. Then many researchers start to use these incandescent lights in the study of photoperiodic response. Then many florescent lights were installed in greenhouse but due to less known about physiology of many plants initially they cause many problems viz. delayed or inhibition of flowering in long day plants. Their use was revolutionized after the Second World War with the invention of different types of effective lamp.

In chrysanthemum, white fluorescent light plants produced smaller leaves than those grown under natural light with shorter internodes (Vince, 1955). Hughes and Cockshull (1971) found that total dry matter production increased in chrysanthemum plants with increase in light irradiation. The effect of light quality differ according to the plant species, developmental stage of the plant, and environmental conditions, medium composition and ventilation, but it is found that dicotyledonous plants are more sensitive to spectral change than monocotyledonous plants (Deutch and Rasmussen, 1974). Light quality influence internode elongation and equal amount of red and far red light increases inter node length. The stem length in chrysanthemum is determined by number of leaves and internodal length; and it is influenced by quality and quantity of light (Calthy, 1974). Vegetative growth is affected by photoperiod by influencing the number, production rate and morphology of leaves, and stem length of plants. The rate of leaf initiation in chrysanthemum under long day condition varied between varieties, but it was not correlated with the number of leaves. The average number of leaves produced by plants under artificial long day condition was significantly higher as compare to plants grown under normal light. Under long day condition, leaves became longer and broader and there a varietal difference was observed in the rate of leaf initiation (Cockshull, 1976).

First study in manipulation of light quality to control the growth of ornamental plants was done by Mortensen and Stromme in the year 1987, by growing many species in the growth cabinet. Blue light has important role in the chlorophyll formation, development of chloroplast, opening of stomata and photo-morphogenesis (Cosgrove, 1981). At higher light intensities, chrysanthemum plants generally flower earlier (Karlsson *et al*., 1989). Hangarter and Stasinopoulos (1991) proposed that the Light filtered to evacuate UV and blue wavelengths improved development, while white fluorescent light diminished the growth because of photochemical modifications of the way of culture medium as opposed to photo-sensory functions of the plant tissues.

Red light has been found important for the development of the photosynthate and carbohydrate accumulation in several plant species (Saebo *et al.,* 1995). Light quality also affects the anatomical structure of plant leaves (Schuerger *et al.,* 1997). Although, in chrysanthemum long days result a sufficient stem length; but it delays the transition to flowering. Supplemental blue lighting has important functions in the flowering process. The application of supplemental lighting also allows greenhouse crops to promote biomass accumulation by increasing photosynthetic carbon assimilation (Hao and Papadopoulos, 1999).

Oyaert *et al.* (1999) reported that several spectral filters were tested on *Chrysanthemum morifolium* 'White Reagan', as an alternative for chemical growth regulators. Three blue polyethylene (PE) films and one vaporized interference film were compared to four neutral filters with corresponding PPFD transmittances (differing from 25% to 73%). The blue PE films had blue: red ratios (B: R) from 6.2 to 85.5 with increasing pigment concentration, and red: far red ratios (R: FR_n) between 0.43 and 1.45. The vaporized film had a relative low B: R (1.41) and a high R: FR_n (2.06). B: R and R: FR_n of the control filters were ≈1. All coloured filters altered plant habit drastically. Under the blue PE films, the inhibition of stem elongation was found increased with increasing pigment concentration, and maximum of 22% growth reduction was recorded compared to the control. Internodal length was significantly shorter but fewer leaves were developed under all coloured filters compared with corresponding controls. Lower number of axillary shoots, a smaller leaf area and a lower total dry weight was recorded under blue filters than the control filters. Furthermore, dry weight was trans-located from stem to leaves. The vaporized film, which was characterised by the highest light transmission percentage, resulted in a relative small growth reduction compared to the corresponding control.

Kubota *et al.* (2000) investigated the impacts of red and far-red-rich spectral (R- and FR-rich) treatments on the growth, development and morphological changes of Petunia under diurnal temperature alternations (DIF). The light spectrum treatments were made by utilizing plastic films containing photo-selective dye compounds. Main stem elongation inhibited under R-rich treatment compared to the control and the FR-rich treatments. Stem elongation was promoted in positive DIF (high day / low night temperatures, P-DIF), whereas negative DIF (low day / high night temperatures, N-DIF) inhibited stem elongation and flowering compared to the control. The R-rich treatment inhibited the main stem elongation under P-DIF and zero DIF (0-DIF) was comparable to N-DIF; however, flowering was not delayed by the R-rich treatment. The R-rich treatment under P-DIF also improved plant morphology by increasing the size and number of lateral shoots, growth of lateral shoots and the number of flowers on these lateral shoots. Therefore, by creating an R-rich environment with a photo-selective plastic film, compact Petunia plants can be produced (short main stem but more lateral shoots) without interfering the flowering process.

Patil *et al.* (2001) reported that plastic films can be alternative methods for growth control under high temperature and high light intensity when temperature strategies are difficult to apply the effect of growth retardants may be weak. LEDs also affect the bulb let regeneration from the scales of Lilium oriental hybrids; in LEDs higher numbers of bulb lets were observed per explants compare to monochromatic and dark light sources. Combination of blue and red LEDs treatment stimulate the bulb lets growth with increase in size, fresh weight and dry weights (Lian *et al.,* 2002). Nhut *et al.* (2003) demonstrated that the best growth of strawberry plantlets grown *in-vitro* was seen under LED-based lighting with 70% red and 30% blue coloured light, while the ideal aggregate photon flux thickness (PFD) was observed to be 60 µmol m^{-2} s^{-1}. Kim *et al.* (2004) reported that no difference was observed in the number of nodes among the different light treatment but difference is seen in internodal length in chrysanthemum. It was found that most prominent stem length was acquired under R and RFr yet the stem elongation was because of internode prolongation, especially, the third internode where extension was twofold the primary internode elongation.

Franklin (2008) reported that the shade from vegetation has a specific spectral signature which strongly influences on the phytochrome photo-equilibrium due to variation of the R: FR ratio. A plant response related to shade avoidance is neighbour detection, which occurs in response to a reduction of the R: FR ratio due to the reflection of FR light from neighbouring plants but do not necessarily lead to a PAR reduction. In shade intolerant plants viz. Arabidopsis, reduction in the R: FR ratio has numbers of striking effects on plant growth and development. The shade avoidance response is characterized by increased hypocotyl, petiole and stem elongation; erect leaf position; enlargement apical dominance and early flowering. Working in chrysanthemum Kurilcik *et al.* (2008) demonstrates that the blue component in the light spectrum hinders the plantlet expansion and formation of roots and all the while builds the dry weight to fresh weight proportion and substance of photosynthetic pigments. They exhibit photo-morphogenetic impacts in the blue region and its interaction with the fragmentary photon flux thickness (PFD) of the far-red spectrum component. Under consistent partial PFD of the blue component, the length of roots and root number, length of stems, and fresh weight of the plantlets have a corresponded non monotonous reliance on the fragmentary PFD of the far-red component. Working in *Chrysanthemum morifolium* Ramat., Hisamatsu *et al.* (2008) demonstrate that an EOD-FR exposure increase shoot extension and is interceded, at any rate to a limited extent, by expanded responsiveness to GA. Moreover, indicated how light, particularly EOD-FR, affected shoot augmentation. The impact of EOD-FR on advancing augmentation growth was maintained, amid the dark period, as well as in the ensuing light time frame. Moreover, perceptions recommend that dark inversion of certain phytochromes is involved in the assurance of blooming time. The applicability of EOD-FR treatment to lessen the general span of development, while keeping up an adequate stem stature amid cut chrysanthemum production. Nhut and Nam (2010) have made attempts to find the relationship between red (R) and blue (B) light ratios on the regulation of plant growth and morphogenesis, in which he found that plant growth was enhanced under 10% blue LEDs, whereas some cases plant growth was higher under 30% blue LEDs, in a combination of red and blue LEDs. It was also found by Jeong *et al.* (2012) that the supplemental blue light induces the flowering response is chrysanthemum even at more than critical day-length exposing chrysanthemum to blue light, the dry weights of leaves was lowest for those grown under blue light.

Significantly height reduction was found in poinsettia plants when grown under LEDs with a higher portion of B light than provided by the traditional HPS lamps. The internodes and petioles were shorter and the expansion of the leaves and bracts was reduced under LED compared to HPS, resulting in very compact plants (Islam *et al.,* 2012). Jeong *et al.* (2014) reported that the average internode length was increases with increasing blue light duration and the number of internodes was much greater in non budded plants than that of budded plants. Kumar and Singh (2017) reported that chrysanthemum plants exposing to long days (15 hr HPS lamp) for 0, 6, 9, 12 and 15 days; plant height, stem diameter, internodal length and numbers of leaves per plant were found maximum under plants attained for 15 days exposure to long days (15 hr) and found minimum under short days (11 hr).

2.4 Role of photoperiod in flower bud induction

Earlier workers suggested that chrysanthemum require obligate short days for flower bud initiation (Post, 1948). Schwabe (1951) suggested that flower buds, produced by vernalized Chrysanthemum plants under long day condition, cease to grow, and bud die at an early stage under long day, and it produce flower if exposed to short days. Flower buds produced under short day condition can be inhibited by transfer to long days, low light intensity in short days and auxin application. In long day condition flower bud is induced by removal of lateral shoots and re rooting of inflorescence after leaving bracts on its axis. It was also revealed that flower bud can also initiate under in the absence of short days (Vince, 1955).

Chrysanthemum requires short days with uninterrupted dark period condition for flower induction. It requires a photoperiod of 14.5 hours for flower bud initiation and 13.5 hours photoperiod for flower bud development (Furuta, 2004). Plant use light as a source of energy source and as well as environmental signal to reaction to its intensity and direction of flowering. The role of phoreceptors is very important to wide range of specific physiological responses (Takemiya *et al.,* 2005). Influence of both light and temperature is responsible for transition of plants from vegetative to reproductive. The phytochromes, cryptochromes, and Zeitlupe family member contribute this complex regulatory network, either by direct action on key regulators of floral transition or by modulating the diurnal clock, which has a strong influence on photoperiodic flowering (Kobayashi and Weigel, 2007). Light quality and particularly shading also leads to accelerated flowering (Franklin, 2008).

Although, the influence of phytochrome in inducing early flowering in chrysanthemum during the incidental levels of blue light is not yet quantified. However, signal to become generative is perceived in the leaves and sent to shoot apex much before the bud break is apparent. These changes in plant leading to promote growth and flowering are strongly visible under photoperiodic influence as compared to the normal irradiance and chrysanthemum is likely to produce diurnal response followed by bud induction even under long day (LD) conditions (Singh *et al*., 2013).

2.5 Role of photoperiod in flowering

Chrysanthemum has strong sensitivity to the ambient temperature and day length, being short day plant for flowering. For flower bud initiation, continuous minimum dark period of 9-9.5 h is necessary (Post, 1948). Hughes and Cockshull (1971) found that in chrysanthemum flower development is delayed in the low light level and hasten with increasing light level and flower weight increased light level. Many environmental factors affect flowering time in which photoperiod is one of the most important factors; Garner and Allard first discovered the photoperiod in the 1920s. According to photoperiod influences on flower induction and development plants are classified into different response groups. Photoperiodic response is primarily determined by continuous dark period, and it can be referred as critical night length (Vince-Prue, 1975). Armitage and Tsujita (1979) worked in rose hybrid 'Forever Yours' and reported that supplemental lighting affected plant growth, flowering, yield and post harvest life. Supplemental lighting through HPS lamp increased flower yield, stem length and flower grade and keeping quality.

Pietsch *et al.* (1995) worked in *Catharanthus roseus* and reported that supplemental lighting decreased the number of days to flowering and at the same time increased the size of flowers. Flowering in plants is regulated by to break the daily continuous dark period that plants receive. To break the period of darkness, artificial lighting can be provided before dawn, end of the day or during the middle of the night. All these three lighting strategies are effective, for flowering regulation (Thomas and Vince-Prue, 1997). Supplemental lighting with low R: FR ratio suppresses lateral branching in several horticulture plants (Moe, 1997). In addition to this, Whiteman *et al.* (1998) investigated that low R: FR ratio supplemental lighting extend the height of *Campanula carpatica* plants under INC lighting. Previously, chrysanthemums flower were grown only during a narrow season in autumn to take advantage of a natural short days. The usual photoperiod for producing cut chrysanthemums is to provide long day condition for vegetative growth and thereafter short-days for flowering. The time period provided for long days determine size of the plants at flower bud initiation phase and finally the size of plant at finishing stage (Wieland, 1998). *Primula malacoides* 'Primula Lilac' was grown at 16°C or 20°C in blend with short day (8 hours) or long day (16 hours). Time to flower at 16°C expanded from 56 to 64 days as so expanded from 1 week to ceaseless conditions in SD, while LD diminished time to blossom from 64 to 56 days. Flowering time at 20°C differed from 73 to 87 days with extra SD presentation bringing about flower and LD in speedier flowering (Karlsson and Werner, 2002).

Heo *et al*. (2002) reported that stem length in marigold was maximum in blue light as compare with red and mixed radiation from fluorescent lamp with LEDs (blue, red, or far-red). Inhibition to flower bud formation in marigold found under mixed radiation of fluorescent with far-red light (F/Fr) , while in salvia no flower buds were formed in monochromatic red and blue light. Kim *et al.* (2002) found that flowering of LD plants can be delayed by light interruption or exposing to a long photoperiod has a high R: FR ratio. Photoperiod that has higher R: FR ratio produces more compact LDPs of *Petunia* × *hybrid*. Heo *et al.* (2003) found that blue in addition to red LEDs enhanced induction of flower in cyclamen, the number of flower buds and open flowers being most astounding in the plants become under blue in addition to red LED (10 h). Blue and red LEDs alone diminished the flowering reaction. Peduncle (flower stalk) length and flowering time were additionally influenced by photoperiod and light qualities. Peduncle length was 23.8 cm on plants developed under red LED (12 h) treatment however 14 cm on plants become under fluorescent light. Blooming time of flowers grown under fluorescent light was 20 days, though it was 40 days with the plants developed under red LEDs (10 h). The outcomes demonstrate that flowering and ensuing growth of cyclamen can be controlled by controlling photoperiod and light quality.

During the 1940s and 1950s, chrysanthemums revolutionized their production and marketing by manipulation of photoperiod to control the vegetative and flowering stage (Furuta, 2004). Khattak *et al.* (2004) reported that 19% reduction in flowering height in chrysanthemum was recorded when far red radiation was removed by spectral filters and this height reduction effect was most noticed between internodes 6 and 11. By providing favourable environmental condition production and quality of many annuals and herbaceous perennials ornamentals those have a photoperiodic flowering response, can be enhanced. Many Commercial growers use artificial lighting to regulate the flowering of several photoperiod sensitive plants at the beginning or during the middle of the night to regulate flowering of photoperiod-sensitive species. Long day lighting is also used for short day plants to inhibit the flowering and production of vegetative growth for cuttings (Mattson and Erwin, 2005). Pramuk and Runkle (2005) studied the influence of light intensity in time of flower initiation on *Impatiens wallerana* and *Celosia argentea* var. *plumosa*. He reported that as increase in DLI from 5 to 25 mol m^{-2} day^{-1} number of flower and flower bud at the time of first flowering increased.

Dole and Wilkins (2005) suggested that flowering in chrysanthemums is naturally controlled by decreasing the day length in late summer and autumn season with flower production from early autumn to winter. By controlling the photoperiod in protected condition, flowers can available round the year. To maintain vegetative growth for sufficient stem length long days are required before young plants keeping under short days for flowering. Short day plants cannot flower under the long days, in summer and autumn season and thus require a certain period of darkness in daily basis before floral development can start. Islam *et al.* (2005) reported that short days increase stem diameter, total number to opening of flowers and shoot dry weight but delay the time to bud initiation compared to long day. Initial short day is preferred to enhance stem diameter, the number of branches and, flowering buds and flowers.

Biondo and Noland (2006) reported that flowering is the consequence of physiological and biochemical procedures, activity of qualities with the impact of photoperiod. Flowering plants have photoreceptor protein for detecting occasional changes in photoperiod, which give the flag for blooming. Flowering plants have a photoreceptor protein to detect regular changes in day length, which go about as signs to blossom. Photoperiodic reaction to bloom acceptance, start and improvement of many plant species are synchronized incidentally amid the year with night length. The development of blossom being stretches out by utilizing counterfeit light, dark material, dark polythene sheets. Photoperiod control using dark material or night interference lighting might be for controlling blooming.

High light enhance flower bud initiation and development and also increase the flowering compare to low light, this result indicates that *Eustoma* is a quantitative long day plants. In protected condition, these environmental factors are commonly manipulated to control flowering and plant morphology in order to produce crops with specific characteristics in a desired period (Islam *et al.,* 2005). Uniform, rapid and predictable flowering is very important for crop production of ornamentals grown in greenhouse (Runkle and Heins, 2005). Hisamatsu *et al*. (2008), reported that EOD-FR light exposure enhances the stem length and it also reduces the duration of cultivation in *Chrysanthemum morifolium*.

Jiang *et al.* (2010) reported that in chrysanthemum, short day acceptance, it took 4 days to achieve the growing point hypertrophy organize, 8 days to complete involucres primordial differentiation, 12 days to complete floret primordial differentiation, crown arrangement in the chrysanthemum cultivars 'Jingyun'. Curry and Ervin (2010) reported that photoperiod expanded from 9 h to13 h, the aggregate bloom numbers diminished from 45 blossoms to 13 blossoms *Kalanchoe uniflora.* All types of Kalanchoe bloomed when become under photoperiods under extending from 9-12 h and rate of blossoming plants diminished for all species as the photoperiod expanded from 12 h to 14 h. No blossoming happened on plants become under a 15 h photoperiod.

Short day (SD) plants flower when they got night length more than critical; in long day plants, flowering occur when they receive night length less than critical; whereas in day neutral plants, flowering is irrespective of the photoperiod. Flowering in ornamental plants depend on the seasonal variation, change in day length promote the phytochromes in leaves to induction for induce flowering in meristematic region by florigen hormone, which works by induction by photochrome. After induction of florigen the flower buds induced and flowering will occurs in the plant (Mer *et al.,* 2015).

In chrysanthemum plants, under natural short days (ND) in September and October decreased number of days are enough to produce flowers when contrasted with those kept higher duration w.e.f. August and onwards. The plants transferred from LD to ND condition in the time of November and December took more time to achieve commercial flower harvesting stage where as those transferred to ND condition in the months of January and February produced flowers in least number of days, respectively. Flower production in some varieties could be stretched out to end of April however the post harvest quality of flowers produced decreased due to ascend in temperature in

March and April (Kaur and Singh, 2016). Kumar and Singh (2017) reported that chrysanthemum plants exposed to long days (15 h HPS lamp) for 0, 6, 9, 12 and 15 days, respectively delayed flower bud initiation and bud induction appeared at the earliest in short day (11h)treatment with no additional photoperiod while a significant delay was noted under 15 days exposure to long days (15h). Flower opening was also delayed with increasing number of days with additional photoperiod. Bud and flower diameter were largest under plants exposed to 15 long days followed by 12 day exposure while minimum in the plants without an exposure to long days (0).

2.6 Role of photoperiod in plant physiology

It has been reported by Tibbitts *et al.* (1983) that blue light plays an important role in chlorophyll biosynthesis, photosynthesis, enzyme synthesis, stomatal opening and maturation of chloroplast. Blue and red LEDs have been utilized for studies in numerous areas of photo-bio-logical research, viz. morphogenesis (Brown *et al.,* 1995), photosynthesis (Tennessen *et al.,* 1994) and chlorophyll blend (Tripathy and Brown, 1995). In chrysanthemum, greater dry weights of leaves, stems, roots as well as leaf area were under the high irradiance treatments (Gislerod and Nelson, 1997). Physiological responses can be reversible viz. stomata opening or irreversible viz. seed germination. The light duration, quantity, quality and direction varying depending on the seasonal changes, latitude, weather condition, and position of plant communities. Under the plant canopy red and blue light will be at very low intensity but far red and green light will be available at relatively higher intensity. Therefore, light intercepted by plant canopy under such diversified conditions may be measured by multiple light sensors to explore and quantify physiological responses leading to the bud induction processes (Chen *et al.,* 2004).

Lettuce grown under different spectra, it is found that conductance of plants developed for 23 days under (white) CWF (*Cool White Fluorescent*) rose rapidly on illumination to a maximum in the middle of the light period, and then diminished again before the dark period when it was in-significant. However, the most extreme was smaller in plants grown under red–blue (RB), red–blue–green (RBG) and green (GF). Spectral quality during growth influences the diurnal pattern of stomatal conductance. Although the stomatal conductance was smaller in plants grown under RBG than CWF, dry matter accumulation was greater, proposing that stomatal conductance did not limit carbon assimilation under spectral conditions. Temporarily changing the spectral quality of the plants grown for 23 days under CWF influenced stomata responses reversibly. It shows that stomatal conductance is responsive to spectral quality during growth and, temporarily, is not specifically coupled to dry matter aggregation (Hyekim *et al.,* 2004).

Kim *et al.* (2004) reported that highest net photosynthetic rate was under mixed red-blue light spectrum followed by fluorescent light and lowest under blue far red in chrysanthemum plants gown under *in-vitro*. Leaf area, fresh and dry weight were also found greatest under mixed red-blue light while it was found lowest under combination of blue and far red light. Plantlets grown under mixed red-blue light spectrum the growth was found greatest had the smaller number and largest leaf stomata while least growth was seen under BFr where largest number but smallest sized stomata found. Shin *et al.* (2008) working in *in-vitro Doritaenopsis* plants showed that leaf area, leaf fresh and dry weight were highest with plants grown under mixed red-blue LEDs. Carbohydrate and leaf pigment biosynthesis of plants was highest in plants grown under mixed red-blue LEDs compare with monochromic light (red or blue LEDs) and fluorescent treatments. Working in cucumber under different light treatments, Trouwborst *et al.* (2010) studied horizontal as well as vertical light extinction and photosynthetic characteristics of leaf at different leaf layers, and determined total plant production of a greenhouse grown *Cucumis sativus* 'Samona' crop. Plants gown under inter-lighting treatments (80%R + 20%B), leaf mass per area and dry mass allocation to leaves were significantly greater but leaf appearance rate and plant length were smaller. Although leaf photosynthetic characteristics significantly increased in the lower leaf layers under inter-lighting, but total biomass or fruit production did not increase same light treatment.

In *in-vitro* chrysanthemum plantlets, growth and morphology of the plantlets were affected by light quality; increases of fresh weight, dry weight, leaf area and chlorophyll content were greatest under a mix of red and blue light (RB). Net assimilation rate in chrysanthemum, increased rapidly under mixed RB light, whereas it lowers under blue light (Jeong *et al.,* 2014).

Chapter 3

MATERIALS AND METHODS

To instate the objective of research, entitled "Studies on photoperiodic response in *Chrysanthemum morifolium* Ramat." an experiment was conducted during July to December, 2016 in the growth chamber of field laboratory of Centre for Protected Cultivation Technology (CPCT), ICAR-IARI, New Delhi. Field laboratory and the greenhouses are freely located at latitude of 28°35'N, 77°12'E longitude and 228.16 m altitude amsl. *Chrysanthemum* is widely grouped into three groups these are standard, spray and pot-mums. In greenhouse all these groups can be grown but standard type of cultivars are more economical and widely practiced. Now days, pot-mums are also grown under greenhouse till flower bud induction and then they are sent to sale points and demand areas. Mostly the varieties and cultivars with medium duration of flowering are preferred for cultivation under protected conditions. There is an extremely wide choice for chrysanthemum growers to choose varieties differing in colour, form, size, biotic and abiotic resistance, production time, labour input, market demand, price expectation, etc. Therefore, a farmer has to take care of all these aspect while making a decision for cultivation. Specific cultivar and a variety can have its own production potential and growers can easily change from one to another. The average cycle of chrysanthemum production is less than 3 months. Crop regulation under controlled climatic regimes can pave a way to choose the suitable variety/cultivar as an important management instrument to receive higher income. The Detail of the materials and methods for conducting this research are briefly described in this chapter.

3.1 Plant material

3.1.1 Nursery and pre-cultivation

Terminal cuttings of 5-6 cm length were taken from mother plants of both varieties and these cuttings were dipped in rooting hormone (Rootex) and then planted in plug trays filled with a soil less media (a mixture of coco-peat, perlite and vermiculite in a ratio of 3:1:1). After planting of cutting in pro-trays daily two irrigation were given during initial days in morning and evening time and after few days single irrigation was given during morning time. Nutrients were provided through fertigation with 2g/*l* mixture of 19:19:19 NPK at 2-3 days interval. These plug trays were kept under 40 %

shade net until rooting. These plugs became ready for transplanting after 30 days attaining 6-7 leaf stage (Plate 3.1.a). These self-rooted cuttings of *Chrysanthemum* cvs. Zembla and Thai Chen Queen were prepared at Centre for Protected Cultivation Technology (CPCT), Indian Agricultural Research Institute, New Delhi-110012.

3.1.2 Description of cultivars

Zembla: It is a standard cultivar of cut chrysanthemum having an average plant height of 87.5 cm and 6 mm stem diameter with medium sized and star shaped flower, white in colour, ray florets are slightly incurved, 4-4.5cm long and 1.3 cm wide. Leaves are large, pinnately lobed with serrated margins, 10-13 cm long and 5-7.5 cm wide with 1.5-3.5 cm petiole length. This is cultivar is highly suitable for cut flower production, and largely grown under polyhouse /greenhouse.

Thai Chen Queen: This is a standard cultivar of cut chrysanthemum, attains an average a plant height of 56.2 cm plant height. It produces large decorative flower type with yellowish orange colour concave ray florets of 7.5 cm long and a width of 2.5 cm. Leaves are 9.2 cm long and 6.4 cm wide with medium number of lobes and 1.7 cm petiole length. This cultivar is suitable for cut flower production and suitably grown in open fields as well as greenhouse/polyhouse conditions.

3.1.3 Media preparation

Three ingredients coco-peat, perlite and vermiculite were taken for media preparation. Coco-peat is present in the form of brick so it dipped in water overnight for loosening while perlite and vermiculite present in the form of granules and flakes respectively are used directly (Plate 3.1.b). Then these three inert materials, coco-peat, perlite and vermiculite were properly mixed at the ratio of 3:1:1 (volume). Coco-peat holds the moisture, reduces the pH, allow to fast penetration of roots and provide proper aeration. Perlite is a kind of rocky material which absorbs and retains the water for further use and also provides proper aeration to roots. While vermiculite is present in larger flakes which help in breaking down of movement of water during day time against evapo-transpirational losses. Then media was filled in pro-trays and plastic pots for rooting of cutting and transplanting of rooted cuttings, respectively (3.1.c).

3.1.4 Transplanting

Before transplanting, plastic pots were sterilized with 0.25% phosphoric acid in a big tub and keeping the pots into the treated water for 30 minutes. After treating the

a.

b. c.

Plate 3.1 Propagation of plug plants

a. Established plugs; b. Media preparation; c. Pot filled with media

a.

b.

Plate 3.2 Transplanting

a. Plug plants ready for transplanting; b. Plants keeping for hardening under greenhouse

pots, prepared media was filled in pots pressing gently followed by light irrigation. Plug plants (rooted cuttings) were transplanted in the plastic pots of 10 cm diameter and 7.3 cm depth in evening time and then placed under greenhouse (Plate 3.2.a). After transplanting light irrigation was given and from next day onwards, daily irrigation was done through rose-cane. For fertigation, distilled water was demineralised by $NaHCO_3$ (124.5g), $CaCl_2$ (99.2g) and $CuSO_4$ (1.2g) dissolved separately and a final volume 10*l* after adjusting the pH (6.5-6.8) was made adding distilled water. Nutrients solution was then made mixing 2g/*l* mixture of 19:19:19 NPK and micronutrients (2.5g/*l* multiplex solution) in demineralised water given as foliar spray. These potted plants were kept for healing under long days (LD) under semi climate controlled greenhouse before being exposed to photoperiodic treatment through LEDs (Plate 3.2.b).

3.2 Experimental set up

After sufficient healing, plants of Zembla and Thai Chen Queen were placed under growth chamber for the experimentation on 10th August, 2016 and 15th October, 2016 respectively (Plate 3.3). The day and night temperature maintained at $24 \pm 2^{\circ}$C and relative humidity regulated at 60-65% through air conditioners and humidifiers, respectively. Two air conditioners were used alternatively for controlling temperature through automatic system setting timers. In growth chamber there were five different grow- boxes of 1.0m × 1.0m sizes glued together and divided to achieve light of different spectrum through coloured LEDs without interfering lighting in another grow-box. The light intensity of all panels was measured before placing the plants under growth chamber and it was found standard level. Plants were kept under artificial long day conditions of 15 h photoperiod and 110 ± 5 µmol m^{-2} s^{-1} LED irradiance of different treatments of light (W, B, R, R80% + B20%) along with control i.e. 11 h under normal light and 110 ± 5 µmol m^{-2} s^{-1} irradiance. The light intensity was measured at weekly interval and potted plants were re-positioned at every 4-5 days so that every plant could get the equal amount of light for their proper growth and development. Regular watering was done manually and nutrients application was followed as per the standard package of practices. The experimental plants per treatment were replicated three times inside grow-box in Completely Randomized Block Design (CRBD).

Treatments: In the experiment, chrysanthemum plants were exposed to LEDs for 15 hr duration as long day exposure and for 11h (control) with HPS lighting. Different wavelength composed of White (W), Blue (B) and Red (R) LEDs (light emitting diode) at 15 h each exposed with 110 μ mol m^{-2} s^{-1} and control with HPS lamp for 11 h @ 110 μ mol m^{-2} s^{-1}. The composition of Red (R) and Blue (B) were provided as admixture of 80%Red and 20%Blue LEDs.

3.3 Stages of observation

The plants were placed on the grow-benches in the greenhouse and nutrition was given through fertigation with 2g/l of 19:19:19 mixture of NPK on daily intervals. Plant protection measures were applied during the entire period of the experiment as per requirement. Cleaning and weeding operation were done timely as per requirement. In growth chamber along with regular fertigation, macronutrients were foliar sprayed at weekly intervals. Observation on plant growth, morphological and physiological parameters were taken at 15 days interval (0, 15th, 30th and 45th days after planting). At the time of flower bud initiation and flower development, flowering observations were taken and recorded.

3.4 Morphological observations

3.4.1 Plant height (cm)

Plant height is the shortest vertical distance between the upper boundaries of the main photosynthetic tissues (excluding inflorescences) on a plant and shoot base at the ground level. Five plants are randomly selected from every replication and height of these plants was measured (cm) at 0, 15, 30 and 45 days after planting. Mean value of these five plants was calculated as an average and recorded.

3.4.2 Stem diameter (mm)

It is the width of stem above the ground level. Stem diameter (mm) was recorded from 5th - 6th node of plant from the base by using vernier caliper. Five plants were randomly selected from each replication and their mean value was calculated as an average and obtained data recorded.

3.4.3 Internodal length (cm)

The distance between two nodes from which leaves emerge is called internode, and length of this internode is called internodal length. From every replication five plants were selected randomly and average of all internodal length (cm) from each plant was measured by using scale from ground level to top of the plant. Mean value of these five plants was calculated as an average and calculated data recorded.

a.

b.

c.

d.

e.

f.

Plate 3.3 Plants under treatments of light

a. Light tratments; b. White LEDs; c. Blue LEDs, d. Red LEDs; e. 80% Red+20%Blue LEDs; f. Control (HPS lamp)

3.4.4 Number of leaves per stem

Total number of leaves from ground level to main photosynthetic tissues (excluding inflorescences) were measured. For each replication five plants were selected randomly and average of them calculated and recorded.

3.4.5 Leaf area (cm^2)

All the mature leaves of the randomly selected five plants from each replication were taken and measurement was carried out by using LI-3100 area meter (LI-COR). Measurement was taken precisely so that no leaves should be overlapped and average mean is calculated and recorded.

3.4.6 Time taken for bud induction (days)

Number of days taken from keeping plants into growth chamber to flower bud initiation on visual basis. Five plants were randomly selected from each replicated treatment and bud initiation time is recorded from each plant. Then the mean value is calculated and recorded.

3.4.7 Bud diameter (mm)

Bud diameter was measured when the bud is fully turgid and attained the full size before the opening of florets. Five plants were randomly selected from each replicated treatment and measurement is taken. The mean value was ascertained and recorded.

3.4.8 Time taken for flower opening (day)

Time taken from keeping plants into growth chamber to full bloom stage was recorded from five randomly selected plants from each replicated treatments. The mean values was ascertained and recorded.

3.4.9 Flower diameter (cm)

At fully opened stage, diameter of flower was measured using scale from five randomly selected plants from each replicated treatments. Mean value of flower diameter was ascertained and tabulated.

3.4.10 Cut flower stem length (cm)

It is the vertical distance from cut portion of flower near ground level till flower head. Five plants were randomly selected from each replicated treatment and measurements were taken when flower is fully open. Mean value of cut flower stem length was calculated and tabulated.

3.5 Physiological parameters

3.5.1 Crop growth rate (g m^{-2} day^{-1})

Five plants were randomly selected from each replicated treatment and dry weight of whole plants above ground level was calculated at 0, 15th, 20th and 45th days after planting; following formula was used to calculating crop growth rate (Watson, 1947).

$$CGR= (W_2-W_1)/GA\ (T_2-T_1)$$

(W_1, W_2 - weight of sample during a period; GA- ground area; T_1, T_2 - Time period)

3.5.2 Relative growth rate (g g^{-1} day^{-1})

Dry weight of whole plants above ground level was measured at 0, 15th, 20th and 45th days after planting from randomly selected five plants from each replicated treatment. Relative growth rate is calculated by using following formula (Fisher, 1920).

$$RGR= logeW_2-logeW_1/\ T_2-T_1$$

(W_1, W_2 - weight of sample during a period; T_1, T_2 - Time period)

3.5.3 Net photosynthetic rate (µmol m^{-2} s^{-1})

Five plants were randomly selected from each replicated treatment and net photosynthetic rate was measured by using an Infra Red Gas Analyzer (LI-COR, Biosciences, USA, Model LI 64000) at 0, 15th, 30th and 45th days after planting. This IRGA system was furnished with air supply unit and a broad leaf chamber (6.25 cm^2). Fully expended 4th leaf from the apical portion was used for the measurement. The light condition of leaf chamber was calibrated to compare real-time light conditions by adjusting the LEDs back panel. By using a CO_2 gas cylinder, the CO_2 concentration of entering air to the leaf chamber was adjusted to 400 $mmol^{-1}$. Leaf temperature was fixed at 22°C. The data were logged at every 30 seconds for 30 minutes.

3.5.4 Stomatal conductance (mmol m^{-2} s^{-1})

Five plants were randomly selected from each replicated treatment and stomatal conductance was measured by using an Infra Red Gas Analyzer (LI-COR, Biosciences, USA, Model LI 64000) furnished with air supply unit and a broad leaf chamber (6.25

cm^2) at 0, 15th, 30th and 45th days after planting. Fully opened 4th leaf from top was used for measurement and light condition of leaf chamber was calibrated to compare real-time light conditions by adjusting the LEDs back panel. CO_2 concentration of entering air was adjusted to 400 $mmol^{-1}$ by using a CO_2 gas cylinder. Leaf temperature was fixed at 22°C and data were logged at every 30 seconds for 30 minutes.

3.5.5 Net assimilation rate (mg cm^{-2} day^{-1})

Dry weight and leaf area of five randomly selected plants from each replicated treatment was measured at 0, 15th, 30th and 45th and Net Assimilation Rate was calculated at 15 days interval by using following formula as per the method suggested by Gregory, 1926.

$$NAR= W_2-W_1 (InLA_2-LA_1)/T_2-T_1 (LA_2-LA_1) \text{ mg cm}^{-2} \text{ day}^{-1}$$

(W_1, W_2 - weight of sample during a period; LA_1, LA_2 - leaf area during a period; T_1, T_2 - Time period)

3.5.6 Leaf area index

Leaf area index is a dimensionless variable and was first suggested by Watson, 1947 as the total one sided area of photosynthetic tissue per unit ground surface area. LAI is utilized to anticipate photosynthetic primary production, evapo-transpiration and reference as a tool for crop growth. It was measured by collecting half developed leaves from bottom to top of whole plant. Five plants from each replication were selected randomly and their total leaf area was measured by using LI-3100 area meter (LI-COR). It is measured by dividing total leaf area of the plant divided by ground area.

$$LAI= \text{Total leaf area}/\text{Ground area}$$

3.5.7 Leaf fresh weight (g)

Five plants were randomly selected from each replicated treatment and a pan balance of 0.01g accuracy was used to measure fresh weight of leaves. After taking the fresh weight, leaves were dried in hot oven at 60°C for 24 h and a pan balance of 0.01g accuracy was used to measure dry weight of leaves. The mean values of these leaf weights were ascertained and recorded.

3.5.8 Leaf dry weight (g)

After taking the fresh weight, leaves were dried in hot oven at 60°C for 24 h and a pan balance of 0.01g accuracy was used to measure dry weight of leaves. Then mean values of these weights were ascertained and recorded.

3.5.9 Stem fresh weight (g)

Five plants were randomly selected from each replicated treatment and a pan balance of 0.01g accuracy was used to measure fresh weight of stem. The mean values of these weights were ascertained and recorded.

3.5.10 Stem dry weight (g)

After measuring the fresh weight, stem were dried in hot oven at 60°C for 24 h and a pan balance of 0.01g accuracy was used to measure dry weight of stem. The mean values of these stem weights were calculated and recorded.

3.5.11 Flower fresh weight (g)

Fully opened flower from five randomly selected plants of each replicated treatment were selected and their fresh weight was measured with a pan balance of 0.01g accuracy. Mean value of flower fresh weight was ascertained and recorded.

3.5.12 Flower dry weight (g)

After taking the fresh weight, flowers were dried in hot oven at 60°C for 24 h and a pan balance of 0.01g accuracy was used to measure dry weight of leaves. Mean value of dry weight of flowers was ascertained and recorded.

3.6 Statistical analysis

The experiment was conducted under growth chamber and climate controlled greenhouse where homogenous conditions maintained. Experimental set-up was a complete randomized block design (CRBD). The recorded data was analyzed for analysis of variance (ANOVA) to explore the main and interaction impacts of treatments were tested at the 5% level of significance. The statistical package OPSTAT version was used for analysis and required graphs were drawn using MS Excel software.

Chapter 4

RESULTS

The investigation entitled "Studies on photoperiodic response in *Chrysanthemum morifolium* Ramat." was conducted to know the response of photo-synthetically active radiation (PAR) through smart LEDs. Chrysanthemum is a short day (SD) plant and under favourable environmental conditions it can produce flower round the year under greenhouse. To attain the sufficient vegetative growth, to obtain self rooted cuttings and post planting growth before flowering, chrysanthemum plants need long days (LD) for several weeks. Under long day (LD) conditions, plant produce long stems which are preferred for cut chrysanthemum in domestic and export markets. Chrysanthemum exposed to sufficient long day period needs short days for flower bud initiation. Genetically, *Chrysanthemum* is light sensitive, where phytochrome reaction in leaves generate a signal which travels to the apex to initiate a flower primordia. The time taken for bud appearance is to be known precisely under the effect of photoperiodic lighting. This reaction time is different in different cultivars depending on their genetic inheritance for photo-thermo sensitivity. It has been established that in chrysanthemum a differential change in light spectrum and temperature can shift the flowering period significantly. The change light integrals from red to far red ratio enable plants to induce flower bud. Owing to the fact that light absorption peaks are only in the Red and Blue zone of the natural light spectrum. An exposure to PAR from LEDs has been found most efficient to transform chrysanthemum from vegetative to generative without countering the dark period even under long day periods (Singh *et al.*, 2013). Therefore, for production of year round quality cut stems in chrysanthemum, long days are to be provided in winter months through supplemental lighting while in the summer, crop either need to be covered with black-sheet to cut natural day light (Horridge *et al.,* 1984) or crop may be exposed with short days (SD) with PAR from smart LEDs . Therefore, an experiment was conducted with chrysanthemum providing LD and SD period using PAR to achieve a normal flower induction along with sufficient vegetative growth. Whether there is a possibility to regulate the crop growth along with quality cut flowers under an artificially extended day length was aimed and attempts were made. Results obtained in the current experiment are being presented and described under the following headings.

4.1 Objective I.

To study the effect of photoperiod on vegetative growth in chrysanthemum using different coloured LEDs.

4.1.1 Plant height (cm)

A significant increase in plant height was recorded when exposed to different light treatments from LEDs (Table 4.1 and Fig. 4.1) in both the cultivars, Zembla and Thai Chen Queen. Plant height was recorded at each 15 days interval at 0, 15, 30 and 45 days. It was maximum (66.50 and 44.57 cm in Zembla and Thai Chen Queen, respectively) under blue LEDs at 45th days. Plants kept under a mixture of Red (80%) + Blue (20%) LEDs exhibited a significantly higher plant height than those kept under other treatments. Plants grown under Red LEDs were found shortest and attained a height of 54.17 cm in Zembla and 33.17 cm in Thai Chen Queen recorded at 45th days. Plants of cultivar, Zembla exhibited an increase in plant height by 17.9% under Blue LEDs over the plants under control (HPS lighting) which was 11.8% higher in plants exposed with an admixture of Red + Blue LEDs. However, the plants of cultivar, Thai Chen Queen showed 27.2% increase in plant height under Blue LEDs and 18.8% in plants kept under mixed Red + Blue LEDs as compare to the plants under control. A significant reduction in plant height was recorded due to Red LEDs in both the cultivars which were less those grown under control (56.40 cm in Zembla and 35.03 cm in Thai Chen Queen, respectively).

The values given in the parenthesis are percent increase in the plant height attained under the influence of the different treatment with LEDs as compared with the plants grown under HPS lighting as control. Comparative analysis shows that increase in plant height was recorded maximum in Zembla (280%) at 45 days after planting due to an exposure of Blue LEDs, 258.7% under an admixture of 80%Red and 20% Blue LEDs while a minimum percent increase in plant height (206%) was recorded in the plants exposed with Red LEDs. Whereas, Thai Chen Queen exhibited a maximum percent increase (184.4%) in plant height illuminated with Blue LEDs while minimum (114.4%) under Red LEDs at 45 days.

4.1.2 Stem diameter (mm)

Table 4.1 Effect of photoperiodic response on plant height in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Plant height (cm)							
	Zembla				Thai Chen Queen			
	Day (0)	Day (15)	Day (30)	Day (45)	Day (0)	Day (15)	Day (30)	Day (45)
White	17.53	31.13 (77.58%)	47.03 (168.3%)	58.17 (231.8%)	15.60	22.17 (42.12%)	29.53 (89.29%)	36.47 (133.8%)
Blue	17.50	34.60 (97.71%)	52.17 (198.1%)	66.50 (280.0%)	15.67	24.57 (56.80%)	33.47 (113.6%)	44.57 (184.4%)
Red	17.70	30.23 (70.79%)	44.23 (149.9%)	54.17 (206.0%)	15.47	21.03 (35.94%)	27.07 (74.98%)	33.17 (114.4%)
Red + Blue	17.57	33.23 (89.13%)	50.23 (185.9%)	63.03 258.7%)	15.53	23.47 (51.13%)	31.87 (105.2%)	41.60 (167.9%)
Control**	17.53	31.00 (76.84%)	46.03 (162.6%)	56.40 (221.7%)	15.57	21.60 (38.72%)	28.17 (80.92%)	35.03 (125.0%)
SE(m)± C.D. (0.05)	0.10 NS	0.32 1.03	0.40 1.26	0.61 1.96	0.07 NS	0.31 0.98	0.45 1.45	0.54 1.73

*PAR exposure @ 110 µmol m^{-2} s^{-1} ; **HPS Light ; Increase in values is given in parentheses

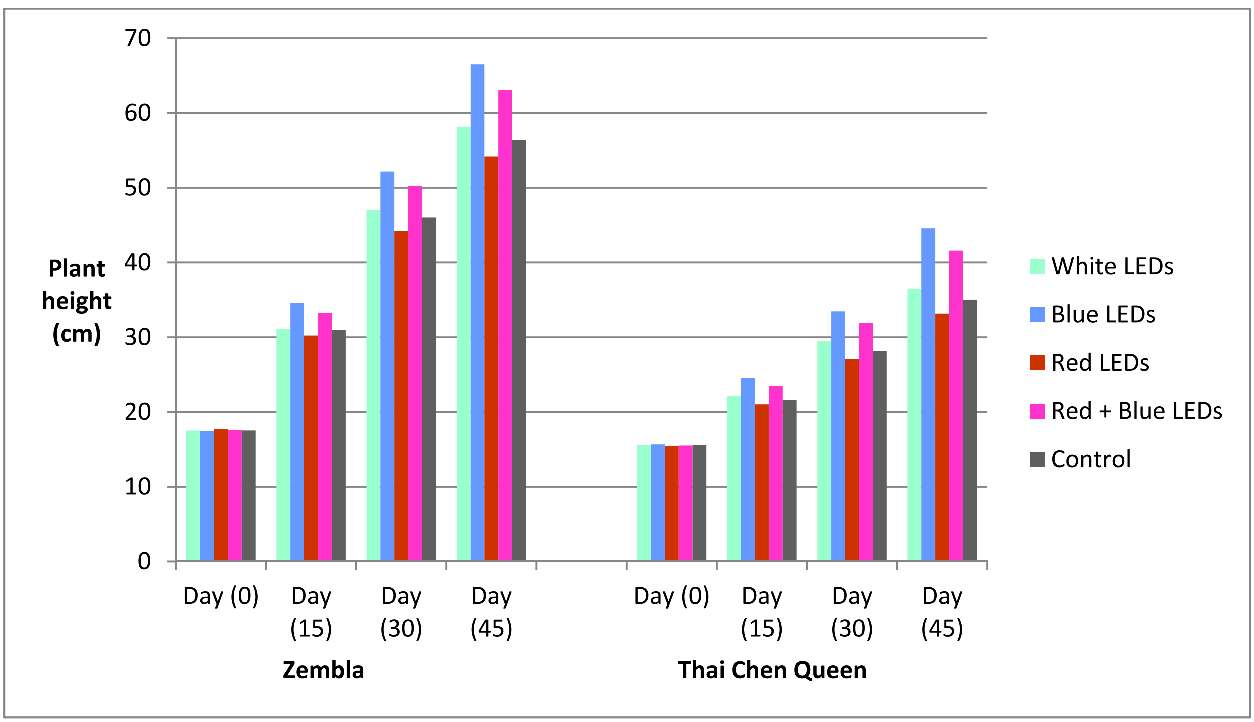


Figure 4.1 Effect of photoperiodic response on plant height in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Table 4.2 Effect of photoperiodic response on stem diameter in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Stem diameter (mm)							
	Zembla				Thai Chen Queen			
	Day (0)	Day (15)	Day (30)	Day (45)	Day (0)	Day (15)	Day (30)	Day (45)
White	3.27	3.68 (12.53%)	4.27 (30.58%)	4.87 (48.92%)	3.17	3.77 (18.92%)	4.37 (37.85%)	4.97 (56.78%)
Blue	3.33	3.57 (7.20%)	4.13 (24.02%)	4.63 (39.03%)	3.20	3.53 (10.31%)	4.17 (30.31%)	4.77 (49.06%)
Red	3.30	3.87 (17.27%)	4.63 (40.30%)	5.60 (69.70%)	3.20	3.90 (21.87%)	4.67 (45.94%)	5.53 (72.81%)
Red + Blue	3.37	3.77 (11.87%)	4.40 (30.56%)	5.37 (59.34%)	3.23	3.83 (18.57%)	4.47 (38.39%)	5.23 (61.92%)
Control**	3.33	3.65 (9.90%)	4.33 (30.03%)	4.90 (47.15%)	3.23	3.77 (16.72%)	4.40 (36.22%)	5.03 (55.73%)
SE(m)±	0.08	0.04	0.06	0.10	0.05	0.07	0.08	0.09
C.D. (0.05)	NS	0.14	0.19	0.31	NS	0.21	0.27	0.28

*PAR exposure @ 110 µmol $m^{-2} s^{-1}$; **HPS Light ; Increase in values is given in parentheses

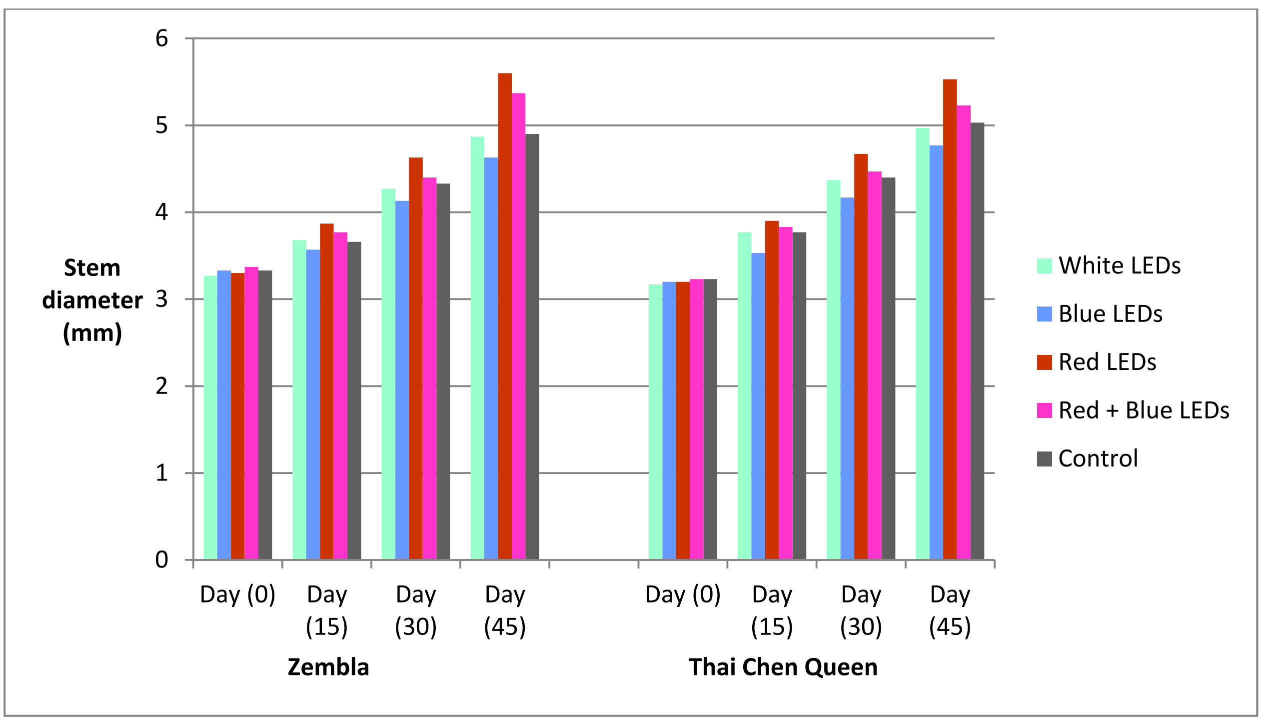


Figure 4.2 Effect of photoperiodic response on stem diameter in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Plants exposed with different treatments with LEDs showed a significant increase in stem diameter recorded in both the cultivars (Table 4.2 and Fig. 4.2) at 45th days. Stem thickness under Red LEDs was observed maximum (5.6 mm) and minimum (4.87 mm) under White LEDs exhibiting 69.7% and 48.92%, respectively over 0 days in cultivar, Zembla. Effect of White LEDs remain at par with control (HPS lighting) and attained a stem diameter of 4.90 mm at 45 days registering an increase by 47.15%. A similar response on stem thickness was recorded in cultivar, Thai Chen Queen and a maximum stem thickness (5.53 mm) was attained in the plants exposed with Red LEDs followed by an admixture of Red + Blue LEDs (5.23 mm). However, plants exposed with White LEDs could gain minimum stem thickness (4.97mm) and remain at par with plants grown under control (5.03 mm). A significantly less thick stems were produced by the plants exposed under Blue LEDs (4.63 mm in Zembla and 4.77 mm in Thai Chen Queen, respectively). The plants grown under the mixed Red + Blue LEDs remain comparatively thicker as compared with all other treatments except Red LEDs.

A pronounced increase was observed in attained stem thickness by the plants exposed with Red LEDs and exhibited a highest percent increase (69.7%) at 45 days in cultivar, Zembla. However, a least per cent increase (39.03%) was recorded in the plants exposed with Blue LEDs at 45 days. The plants exposed with a mixture of Red + Blue LEDs registered a significant percent (59.34%) increase in stem diameter at 45 days in Zembla which remain at par with the plants of cultivar, Thai Chen Queen (61.92 %). However, plants of Thai Chen Queen attained a maximum percent increase (72.81%) in plant diameter was noted in the plants illuminated with Red LEDs (72.81%) followed by Red LEDs (45.94%) at 30 days while minimum stem diameter was recorded under Blue LEDs (10.31%) at 15 days.

4.1.3 Internodal length (cm)

A significant effect of photoperiod through different coloured LEDs was recorded on internodal length (Table 4.3 and Fig. 4.3) at 0, 15th, 30th and 45th days after the plants were kept in growth chamber. The longest internodal length (2.29 cm) was recorded in the plants exposed to Blue LEDs followed by mixed Red + Blue (2.18cm) while minimum internodal distance (1.94 cm) was observed in plant raised under Red LEDs at 45 days in cultivar, Zembla. Similar effect of photoperiod on internodal length in Thai Chen Queen due to an exposure of different coloured LEDs and attained maximum under Blue LEDs (1.92 cm) and minimum (1.64 cm) under Red LEDs which showed a percent increase by 12.3% and 7.9% in internodal length in Zembla and Thai Chen Queen respectively, in the plants under Blue LEDs as compare with control. A significant per cent increase in intermodal length was increased under an admixture of Red + Blue LEDs (89.5% in Zembla and 46.03% in Thai Chen Queen) as compared to those raised under control (77.39% in Zembla and 40.16% in Thai Chen Queen) followed by the plants under White LEDs (80.53% in Zembla and 43.9% in Thai Chen Queen) whereas, a significant and lowest percent increase in intermodal length (1.94 cm in Zembla and 1.64 cm in Thai Chen Queen) registering a per cent increase by 68.7% in Zembla and 31.2% in Thai Chen Queen.

Percent increase was compared between treatments for increase in internodal length due to different LEDs and found that in Zembla, maximum percent increase was observed in plants kept under Blue LEDs (100.9%) at 45 days after treatment followed by plants under an admixture of Red + Blue LEDs (89.57%) at 45 days as compared with the minimum under Red LEDs (13.91%) at 15 days. However in Thai Chen Queen , a maximum percent increase in internodal length was recorded under Blue LEDs (51.18%) at 45 days and minimum under Red LEDs (31.20%) at 45 days.

4.1.4 Number of leaves per plant

Number of leaves per plant (Table 4.4 and Fig. 4.4) showed non-significant differences among different treatments with LEDs at 15^{th} and 30^{th} days except at 45 days after planting. However, these differences were negligible at 15 and 30 days and rose to 5.8% and 6.4% higher in cultivars, Zembla and Thai Chen Queen, respectively as compare with control. Maximum number of leaves were recorded in plants exposed with Blue LEDs (32.73 in Zembla and 25.40 in Thai Chen Queen) which remained significantly lesser (30.93 and 23.87 leaves per plant, respectively) in cultivars, Zembla and Thai Chen Queen, respectively. Plants grown under Red LEDs produced minimum number of leaves per plant (7% and 7.5 % lesser) in cultivars, Zembla and Thai Chen Queen respectively as compare with Blue LEDs. The effect of White LEDs on number of leaves produced per plant in Zembla (31.33) and Thai Chen Queen (24.10) remain at par with that of HPS lighting (control) producing number of leaves 30.93 in Zembla and 23.87 in Thai Chen Queen at 45 days after planting.

Number of leaves per plant produced under different treatments with LEDs showed a significant increase and observed that a maximum percent increase in number

Table 4.3 Effect of photoperiodic response on internodal length in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Internodal length (cm)							
	Zembla				Thai Chen Queen			
	Day (0)	Day (15)	Day (30)	Day (45)	Day (0)	Day (15)	Day (30)	Day (45)
White	1.13	1.36 (20.35%)	1.65 (46.02%)	2.04 (80.53%)	1.23	1.43 (16.26%)	1.56 (26.83%)	1.77 (43.90%)
Blue	1.14	1.48 (29.82%)	1.77 (55.26%)	2.29 (100.9%)	1.27	1.51 (18.89%)	1.68 (32.28%)	1.92 (51.18%)
Red	1.15	1.31 (13.91%)	1.53 (33.04%)	1.94 (68.70%)	1.25	1.39 (11.2%)	1.53 (22.40%)	1.64 (31.20%)
Red + Blue	1.15	1.42 (23.48%)	1.72 (49.57%)	2.18 (89.57%)	1.26	1.47 (16.67%)	1.63 (29.37%)	1.84 (46.03%)
Control**	1.15	1.35 (17.39%)	1.62 (40.87%)	2.04 (77.39%)	1.27	1.42 (11.81%)	1.57 (23.62%)	1.78 (40.16%)
SE(m)±	0.02	0.01	0.03	0.04	0.02	0.02	0.02	0.02
C.D. $_{(0.05)}$	NS	0.05	0.08	0.12	NS	0.05	0.05	0.05

*PAR exposure @ 110 µmol m^{-2} s^{-1} ; **HPS Light ; Increase in values is given in parentheses

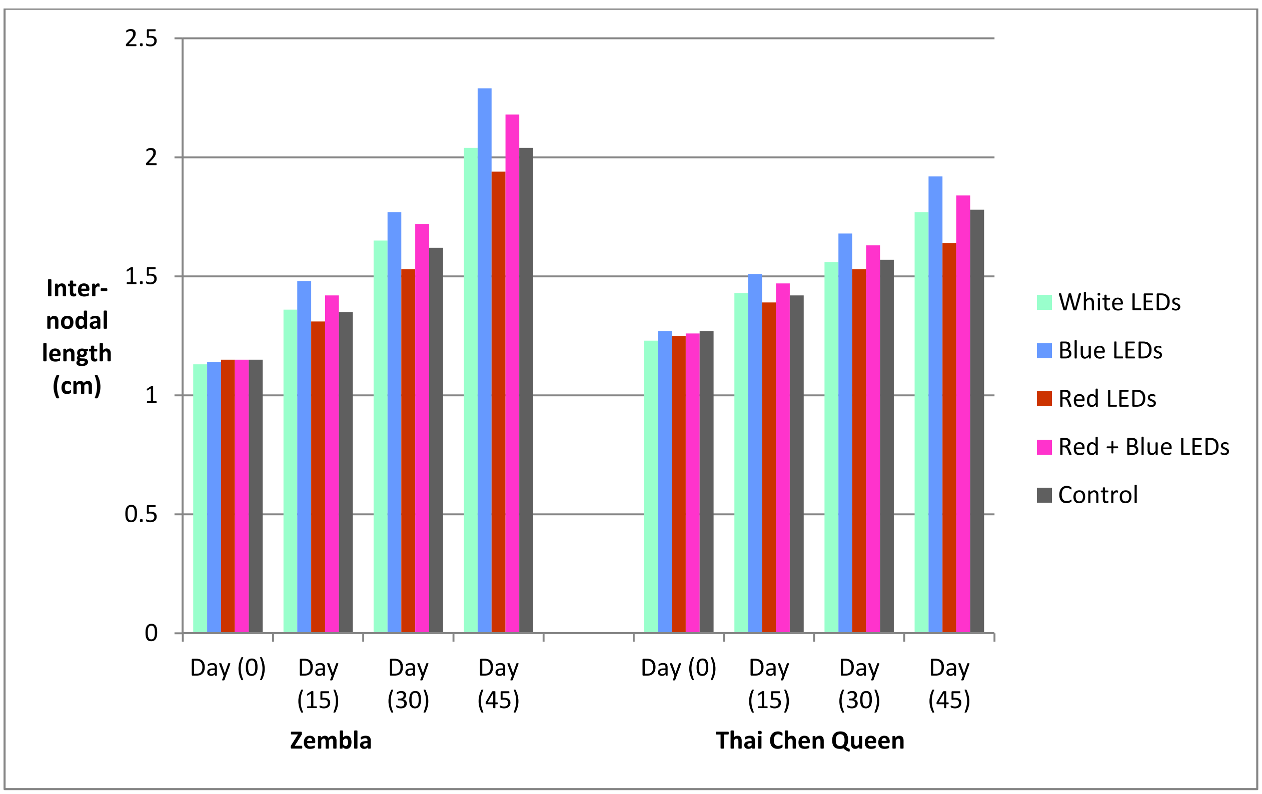


Table 4.3 Effect of photoperiodic response on internodal length in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Table 4.4 Effect of photoperiodic response on number of leaves per plant in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Number of leaves per plant							
	Zembla				Thai Chen Queen			
	Day (0)	Day (15)	Day (30)	Day (45)	Day (0)	Day (15)	Day (30)	Day (45)
White	13.87	22.33 (61.00%)	27.17 (95.89%)	31.33 (125.9%)	13.47	16.50 (22.49%)	21.43 (59.09%)	24.10 (78.92%)
Blue	13.90	23.83 (71.44%)	28.07 (101.9%)	32.73 (135.5%)	12.37	17.23 (39.29%)	22.80 (84.32%)	25.40 (105.3%)
Red	13.17	21.97 (66.82%)	26.63 (102.2%)	30.47 (131.4%)	13.00	16.17 (24.38%)	21.00 (61.54%)	23.63 (81.77%)
Red + Blue	13.83	22.63 (63.63%)	27.70 (100.3%)	32.33 (133.8%)	12.57	16.77 (33.41%)	22.63 (80.03%)	25.03 (99.12%)
Control**	14.20	22.03 (55.14%)	26.83 (88.94%)	30.93 (117.8%)	13.03	16.43 (26.09%)	22.30 (71.14%)	23.87 (83.19%)
SE(m)±	0.48	0.44	0.44	0.36	0.54	0.31	0.52	0.39
C.D. (0.05)	NS	NS	NS	1.14	NS	NS	NS	1.24

*PAR exposure @ 110 µmol m^{-2} s^{-1} ; **HPS Light; Increase in values is given in parentheses

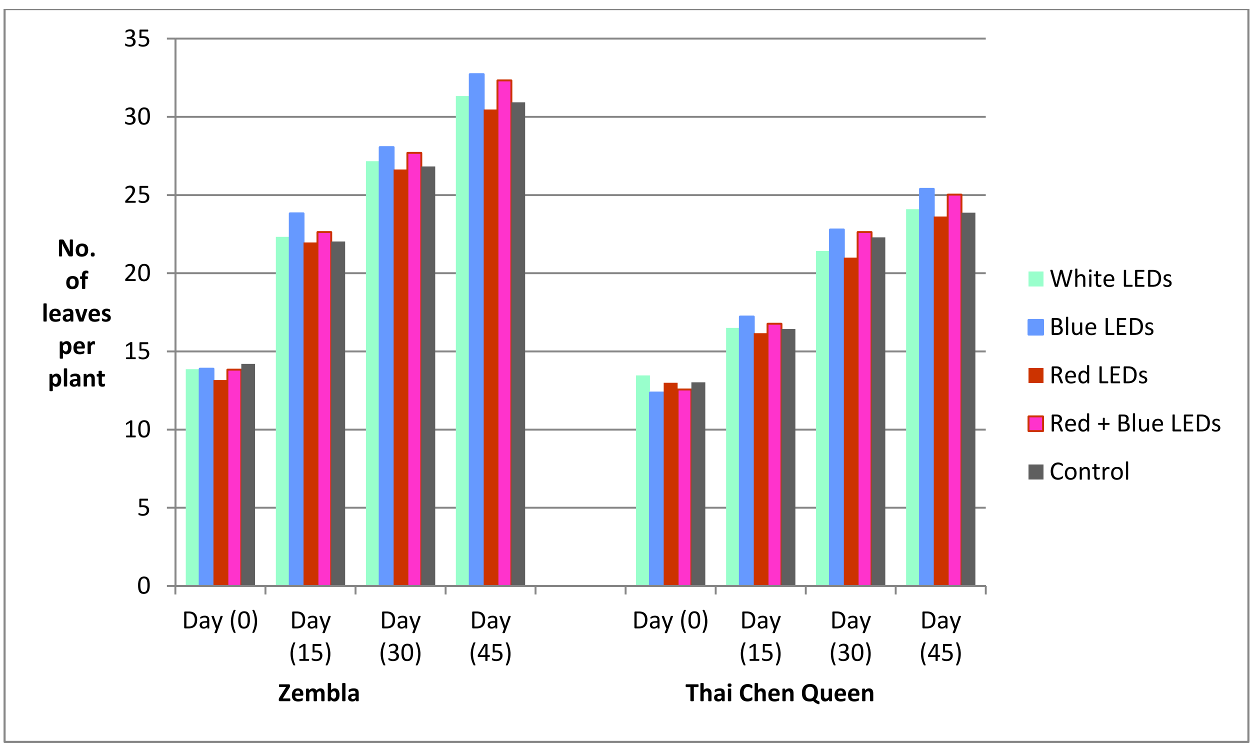


Figure 4.4 Effect of photoperiodic response on number of leaves per plant in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

of leaves per plant was recorded under Blue LEDs at 15 days (71.44%) as compared with the plants grown with HPS lighting (control) at 45 days registering minimum (117.8%) in Zembla and 84.32% in Thai Chen Queen under Blue LEDs at 30 days which remained minimum in the plants grown with White LEDs (22.49%) at 15 days.

4.1.5 Leaf area (cm^2)

Leaf area attained in the plants exposed under different treatments with LEDs showed significant differences among themselves (Table 4.5 and Fig. 4.5) and varied at 15, 30 and 45 days after planting in both the cultivars, Zembla and Thai Chen Queen. Maximum leaf area (291.40 cm^2) was recorded in plants of cultivar, Zembla grown under mixed Red + Blue LEDs and while minimum leaf area (255.67cm^2) recorded under control at 45 days. Similarly, the plants of Thai Chen Queen acquired a maximum leaf area of 192.33 cm^2 when exposed to the admixture of Red + Blue followed by Blue (182.86 cm^2) and Red (180.60 cm^2) at 45 days. However, the lowest leaf area expansion (171.73 cm^2) under control (HPS lamp lighting) which remained at par with the plants exposed with White LEDs (175.10 cm^2). The differences between cultivars for leaf area expansion under the influence of PAR treatment with LEDs showed an increase by 14 % and 12% recorded in Zembla (291.40 cm^2) and Thai Chen Queen (192.33 cm^2) cultivars respectively over the values achieved under control. Increase in average area per leaf under Blue LEDs and Red LEDs differed significantly when compared with plants grown under control and remained at par with plants raised under exposure of White LEDs.

A comparative analysis of increase in leaf area achieved under the influence of PAR from different coloured LEDs was done and found that Zembla plants could attained a maximum percent (66.34%) increase at 15 days after planting due to an exposure of mixed Red + Blue LEDs which rose to 173.3% at 45 days after transplanting followed by Blue LEDs (165.7%). The minimum percent increase in leaf area expansion was estimated (144.4%) in plants grown under HPS lamp lighting (control). Whereas, cultivar Thai Chen Queen registered a maximum increase (37.89%) in leaf area at 15 days when the plants were illuminated with mixed Red + Blue LEDs and rose to a maximum of 83.12% at 45 days. The minimum percent increase in leaf area was recorded under control (65.44%) at 45 days.

4.1.6 Leaf area index

The values obtained for the leaf area index as influenced with exposure of plant under different coloured LEDs (Table 4.6 and Fig. 4.6), a pronounced and significant increase was registered at 15^{th}, 30^{th} and 45^{th} days. A maximum leaf area index was recorded in the leaves of the plants grown under an admixture of Red + Blue LEDs (2.91 in Zembla and 1.92 in Thai Chen Queen) followed by Blue LEDs (2.77 and 1.83, respectively) whereas a minimum leaf area index was observed under control (2.56 in Zembla and 1.72 in Thai Chen Queen, respectively). Between the cultivars it was estimated that the an average leaf area index was increased by 13.7% in Zembla and 11.6% in Thai Chen Queen when the plants were exposed with a mixture of Red + Blue LEDs recorded at 45 days as compared with control.

The cultivars, Zembla and Thai Chen Queen registered a significant increase in percent leaf area index, the maximum being noted for the plants under Red + Blue LEDs (172% and 82.86%, respectively) at 45 days after transplanting. The values obtained reveals that the cultivar, Zembla could attain maximum functional leaf area as compared with the values obtained in Thai Chen Queen. However, the percent values for leaf area index could remain at par with each other in case of the plants exposed with White LEDs (52.83% and 68.27%, respectively) as compared with control (52.38% and 66.99%, respectively).

4.1.7 Leaf fresh weight (g)

A significant effect of different photoperiodic treatments was recorded on leaf fresh weight (Table 4.7 and Fig. 4.7) in both the cultivars, Zembla and Thai Chen Queen at 15, 30 and 45 days. It was found that the leaf fresh weight was recorded highest (15.30g)in the plants exposed with mixed Red + Blue LEDs followed by Blue (14.56g), Red (13.63g) and white (13.15g) LEDs and lowest (12.62g) being in plants grown under HPS lighting (control) recorded at 45 days in cultivar , Zembla. Similar pattern of leaf fresh weight accumulated in the plants of Thai Chen Queen was observed and recorded highest (11.67g) per plant under mixed Red + Blue LEDs and lowest (9.37g) in control. Plants of cultivar, Zembla could produce and increase fresh weight of leaves by 21.2% which is significantly lower than that recorded in Thai Chen Queen (24.5%) under mixed Red + Blue LEDs followed by Blue LEDs and registered an increase by 15.4% and 16.1%, respectively over the fresh weight accumulated in the leaves under control.

Table 4.5 Effect of photoperiodic response on leaf area in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Leaf area (cm^2)							
	Zembla				Thai Chen Queen			
	Day (0)	Day (15)	Day (30)	Day (45)	Day (0)	Day (15)	Day (30)	Day (45)
White	106.33	161.83 (52.20%)	227.33 (113.8%)	263.60 (147.9%)	103.50	136.27 (31.66%)	156.57 (51.28%)	175.1 (69.18%)
Blue	104.17	170.97 (64.13%)	236.53 (127.1%)	276.73 (165.7%)	104.17	140.90 (35.26%)	162.53 (56.02%)	182.86 (75.54%)
Red	104.87	165.17 (57.50%)	234.07 (123.2%)	274.43 (161.7%)	103.03	139.50 (35.40)	161.00 (56.26%)	180.60 (75.28%)
Red + Blue	106.63	177.37 (66.34%)	246.20 (130.9%)	291.40 (173.3%)	105.03	144.83 (37.89%)	165.07 (57.16%)	192.33 (83.12%)
Control**	104.60	160.03 (52.99%)	226.23 (116.3%)	255.67 (144.4%)	103.80	134.17 (29.26%)	152.26 (46.68%)	171.73 (65.44%)
SE(m)±	1.35	3.27	2.61	3.60	1.43	2.00	2.01	2.05
C.D. (0.05)	NS	10.44	8.36	11.50	NS	6.38	6.41	6.55

*PAR exposure @ 110 µ mol m^{-2} s^{-1}; **HPS Light; Increase in values is given in parentheses

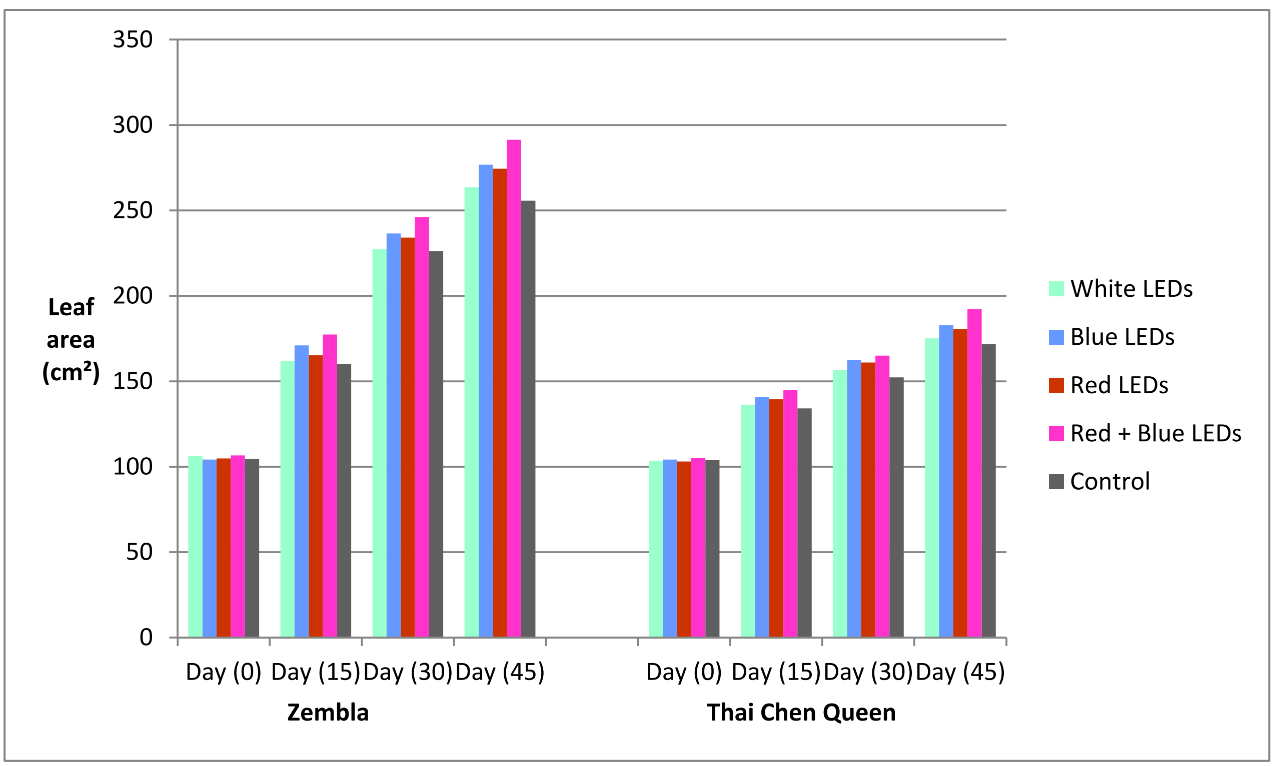


Figure 4.5 Effect of photoperiodic response on leaf area in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Table 4.6 Effect of photoperiodic response on leaf area index in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Leaf area index							
	Zembla				Thai Chen Queen			
	Day (0)	Day (15)	Day (30)	Day (45)	Day (0)	Day (15)	Day (30)	Day (45)
White	1.06	1.62 (52.83%)	2.27 (114.2%)	2.64 (149.1%)	1.04	1.36 (30.77%)	1.57 (50.96%)	1.75 (68.27%)
Blue	1.04	1.71 (64.42%)	2.37 (127.9%)	2.77 (166.3%)	1.04	1.41 (35.58%)	1.63 (56.73%)	1.83 (75.96%)
Red	1.05	1.65 (57.14%)	2.34 (122.9%)	2.74 (161.0%)	1.03	1.39 (34.95%)	1.61 (56.31%)	1.81 (75.74%)
Red + Blue	1.07	1.77 (65.42%)	2.46 (129.9%)	2.91 (172.0%)	1.05	1.45 (38.09%)	1.65 (57.14%)	1.92 (82.86%)
Control**	1.05	1.60 (52.38%)	2.26 (115.2%)	2.56 (143.8%)	1.03	1.34 (30.09%)	1.52 (47.57%)	1.72 (66.99%)
SE(m)±	0.01	0.03	0.03	0.04	0.01	0.02	0.02	0.02
C.D. (0.05)	NS	0.10	0.08	0.12	NS	0.06	0.06	0.07

*PAR exposure @ 110 µmol m^{-2} s^{-1} ; **HPS Light ; Increase in values is given in parentheses

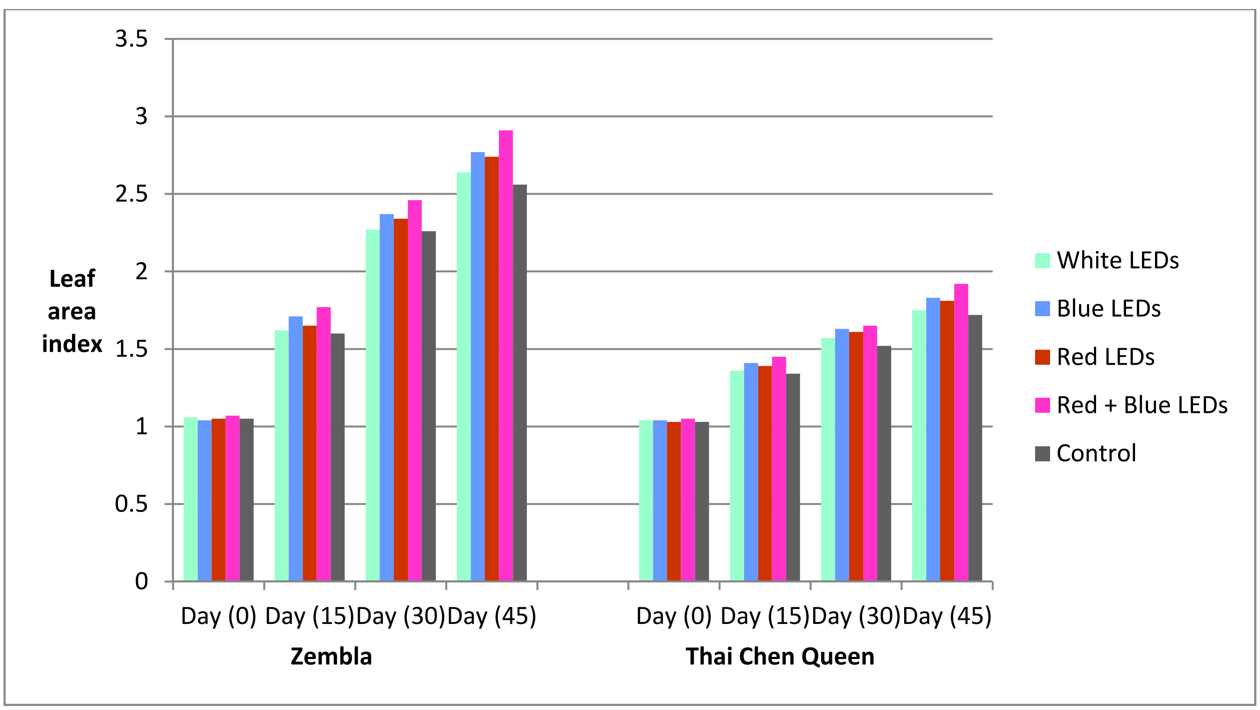


Figure 4.6 Effect of photoperiodic response on leaf area index in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Table 4.7 Effect of photoperiodic response on leaf fresh weight in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Leaf fresh weight (g)							
	Zembla				Thai Chen Queen			
	Day (0)	Day (15)	Day (30)	Day (45)	Day (0)	Day (15)	Day (30)	Day (45)
White	4.56	8.65 (89.69%)	11.62 (154.8%)	13.15 (188.4%)	3.75	6.34 (69.07%)	8.84 (135.7%)	9.82 (161.9%)
Blue	4.56	9.44 (107.0%)	12.52 (174.6%)	14.56 (219.3%)	3.67	6.64 (80.93%)	9.39 (155.9%)	10.88 (196.5%)
Red	4.51	8.74 (93.79%)	11.86 (163.0%)	13.63 (202.2%)	3.76	6.42 (70.74%)	9.10 (142.0%)	10.25 (172.6%)
Red + Blue	4.54	9.82 (116.3%)	13.21 (191.0%)	15.30 (237.0%)	3.79	6.94 (83.11%)	9.85 (159.9%)	11.67 (207.9%)
Control**	4.55	8.63 (89.67%)	11.54 (153.6%)	12.62 (177.4%)	3.60	6.27 (74.17%)	8.61 (139.2%)	9.37 (160.3%)
SE(m)±	0.07	0.10	0.14	0.22	0.12	0.09	0.10	0.15
C.D. (0.05)	NS	0.32	0.44	0.69	NS	0.27	0.31	0.49

*PAR exposure @ 110 µmol m^{-2} s^{-1}; **HPS Light ; Increase in values is given in parentheses

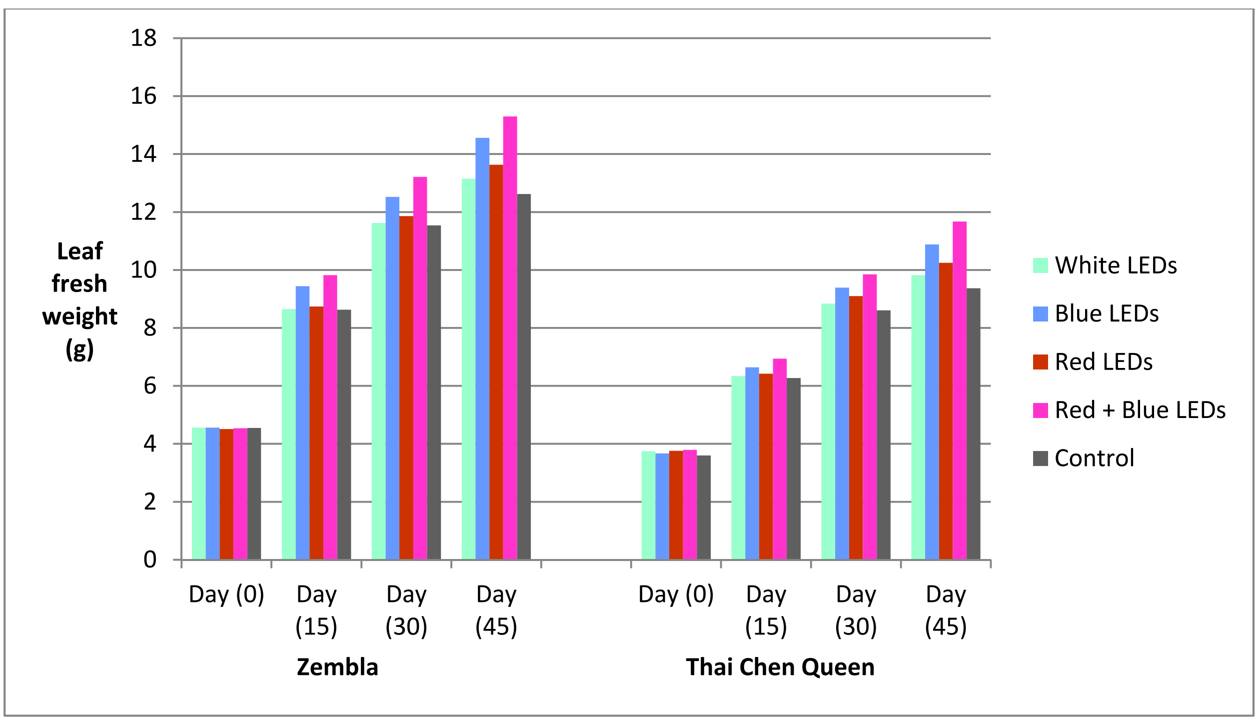


Figure 4.7 Effect of photoperiodic response on leaf fresh weight in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Analysis for an increase in leaf fresh weight was worked out and found that a maximum percent (116.3%) increase was recorded at 15 days after planting due to an exposure of mixed Red + Blue LEDs which rose to 237% at 45 days. However, the values for percent increase in accumulated leaf fresh weight were minimum (177.4%) in plants grown under control in cultivar Zembla. Plants of cultivar, Thai Chen Queen had a maximum percent increase (83.11%) in leaf fresh weight when the plants were illuminated with mixed Red + Blue LEDs at 15 days and minimum in (135.7%) under White LEDs at 30 days.

4.1.8 Leaf dry weight (g)

Leaf dry weight was recorded (Table 4.8 and Fig. 4.8), varied significantly with different treatments with LEDs. Leaf dry weight was recorded highest under mixed Red + Blue at 15 (1.21g and 1.22g), 30 (1.60g and 1.43g) and 45(1.97g and 1.70g) days in Zembla and Thai Chen Queen , respectively while it was recorded lowest in control (1.46g and 1.39g) and White LEDs (1.48g and 1.41g) at 45 days in Zembla and Thai Chen Queen, respectively. A significant increase in leaf dry weight was noted mixed Red + Blue LEDs followed by Blue (1.80g and 1.57g) and Red (1.74g and 1.47g) LEDs in cultivars, Zembla and Thai Chen Queen, respectively. This increase in leaf dry weight accumulated in the plants rose by 34.9% and 22.3% under mixed Red + Blue LEDs remained significant over the values recorded for plants under control.

As shown from that data, Zembla grown under the mixed Red + Blue LEDs produce the maximum comparative growth rate of leaf dry weight (124.1%) followed by plants under Blue LEDs (121.6%) at 15 days. The minimum leaf dry weights were accumulated in the plants under control (180.8%) recorded at 45 days. Where as in Thai Chen Queen, maximum leaf dry weight was recorded as percent (165.2%) increase under mixed Red + Blue LEDs followed by the plants under Blue LEDs (123.9%) at 15 days and minimum under control (183.7%) at 45 days.

4.1.9 Stem fresh weight (g)

A significant effect of different light treatment on the stem fresh weight (Table 4.9 and Fig. 4.9) was recorded at 15, 30 and 45 days after planting under growth chamber with LEDs. Cultivar, Zembla accumulated maximum stem fresh weight recorded at 45 days when grown under mixed Red + Blue LEDs (10.60g) and minimum stem fresh weight (7.36g) in plants under control. Similar results were recorded in cultivar, Thai Chen Queen and attained 7.10g stem fresh weight when exposed with mixed Red + Blue LEDs. Zembla showed an increase in stem fresh weight by 44% over control when grown under mixed Red + Blue LEDs; whereas, Thai Chen Queen was recorded an increase by 35.2%. Plants kept under an exposure with Blue LEDs, Red LEDs and White LEDs gained a significantly higher stem fresh weight compared to the plants under control.

Maximum increase in comparative stem fresh weight was recorded in Zembla grown under Red LEDs (196.7%) at 15 days followed by plants exposed to the mixed Red + Blue LEDs (190.3%),while minimum percent increase in stem fresh weight was recorded in plants illuminated with HPS lamp (377.9%) at 45 days. However in Thai Chen Queen, maximum comparative increase in stem fresh weight was measured in plants exposed to Red (119.9%) and mixed Red + Blue (126.1%) LEDs, while minimum comparative stem fresh weight was noted under plants exposed with HPS light (152.2%) at 30 days but it was significantly higher than that recorded under control.

4.1.10 Stem dry weight (g)

Stem dry stem weight (Table 4.10 and Fig. 4.10) was recorded and varied significantly as influenced by different treatments of LEDs at different stages of plant growth at 0, 15th, 30th and 45th days after transplanting. Cultivar, Zembla could produce maximum stem dry weight, recorded under mixed Red + Blue LEDs (3.16g) while minimum dry stem weight (2.35g) was accumulated in the plants grown under control at 45 days. Similar results were noted for cultivar, Thai Chen Queen registering a stem dry weight of 1.82g and 1.32g, respectively in the plants raised under mixed Red + Blue LEDs and control, respectively. Per cent dry weight increase shown by Zembla (34.5%) and Thai Chen Queen (37.8%) under mixed Red + Blue LEDs remained at par with control which were significantly higher than under Red + Blue LEDs as compared with the plants raised under HPS lighting (control).

Effect of different photoperiodic treatment with LEDs was compared for percent increase in stem dry weight accumulation and it was found that cultivar, Zembla witnessed a maximum increase (989.7%) in stem dry weight, recorded in the plants

Table 4.8 Effect of photoperiodic response on leaf dry weight *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Leaf dry weight (g)							
	Zembla				Thai Chen Queen			
	Day (0)	Day (15)	Day (30)	Day (45)	Day (0)	Day (15)	Day (30)	Day (45)
White	0.52	1.01 (94.23%)	1.27 (144.2%)	1.48 (184.6%)	0.45	0.86 (91.1%)	1.18 (162.2%)	1.41 (213.3%)
Blue	0.51	1.13 (121.6%)	1.49 (192.2%)	1.80 (254.9%)	0.46	1.03 (123.9%)	1.30 (182.6%)	1.57 (241.3%)
Red	0.55	1.10 (100.0%)	1.37 (149.1%)	1.74 (216.4%)	0.48	0.97 (102.1%)	1.27 (164.6%)	1.47 (206.3%)
Red + Blue	0.54	1.21 (124.1%)	1.60 (196.3%)	1.97 (264.8%)	0.46	1.22 (165.2%)	1.43 (210.9%)	1.70 (269.6%)
Control**	0.52	0.97 (86.54%)	1.24 (138.5%)	1.46 (180.8%)	0.49	0.84 (71.4%)	1.15 (132.7.9%)	1.39 (183.7%)
SE(m)±	0.03	0.03	0.04	0.06	0.02	0.03	0.03	0.03
C.D. $_{(0.05)}$	NS	0.10	0.13	0.18	NS	0.11	0.10	0.10

*PAR exposure @ 110 µmol $m^{-2} s^{-1}$; **HPS Light ; Increase in values is given in parentheses

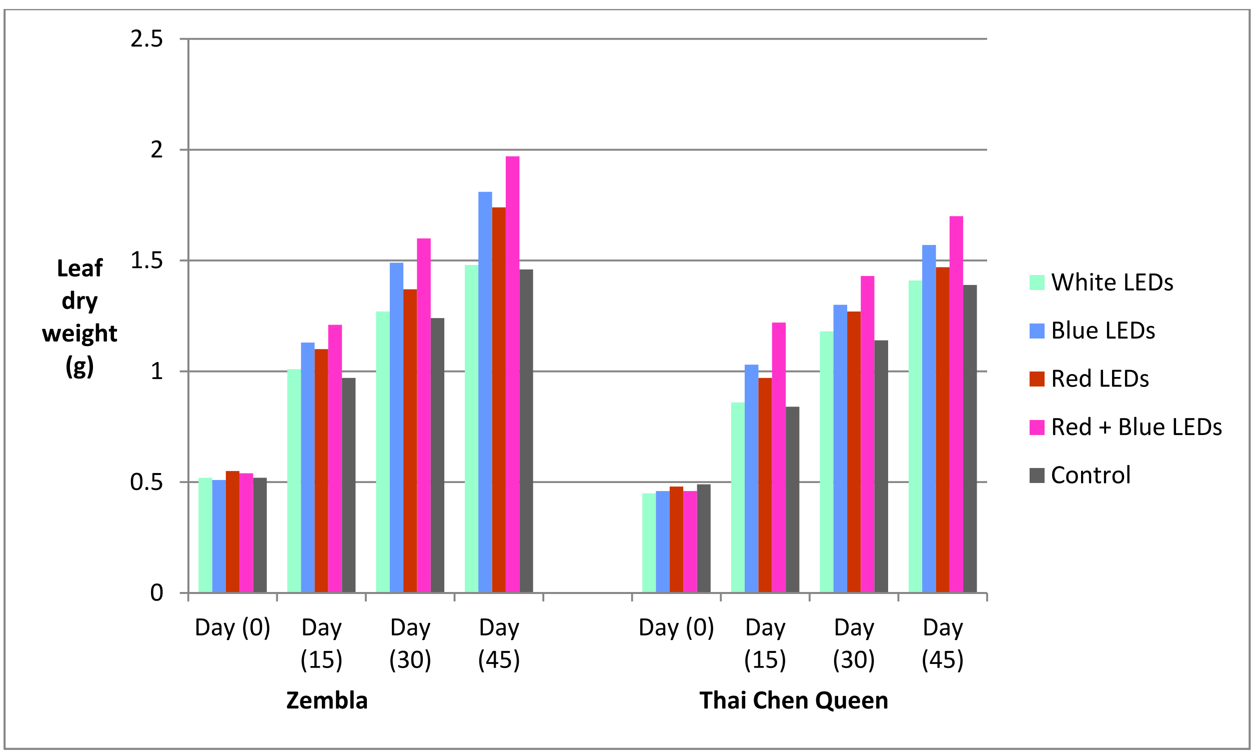


Figure 4.8 Effect of photoperiodic response on leaf dry weight *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Table 4.9 Effect of photoperiodic response on stem fresh weight in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Stem fresh weight (g)							
	Zembla				Thai Chen Queen			
	Day (0)	Day (15)	Day (30)	Day (45)	Day (0)	Day (15)	Day (30)	Day (45)
White	1.66	4.29 (158.4%)	6.63 (299.4%)	8.17 (392.2%)	1.61	3.38 (109.9%)	4.19 (160.3)	5.54 (244.1%)
Blue	1.64	4.58 (179.3%)	7.19 (338.4%)	9.38 (471.9%)	1.54	3.49 (126.6%)	4.94 (220.8%)	6.37 (313.6%)
Red	1.50	4.45 (196.7%)	7.11 (374.0%)	9.14 (509.3%)	1.56	3.42 (119.9%)	4.86 (211.5%)	6.21 (298.1%)
Red + Blue	1.65	4.80 (190.3%)	7.90 (378.8%)	10.60 (542.4%)	1.61	3.64 (126.1%)	5.45 (238.5%)	7.10 (341.0%)
Control**	1.54	4.18 (171.4%)	6.37 (313.6%)	7.36 (377.9%)	1.59	3.32 (108.8%)	4.01 (152.2%)	5.25 (230.2%)
SE(m)±	0.09	0.06	0.12	0.23	0.05	0.04	0.10	0.13
C.D. $_{(0.05)}$	NS	0.19	0.38	0.73	NS	0.16	0.33	0.41

*PAR exposure @ 110 µmol m^{-2} s^{-1} ; **HPS Light ; Increase in values is given in parentheses

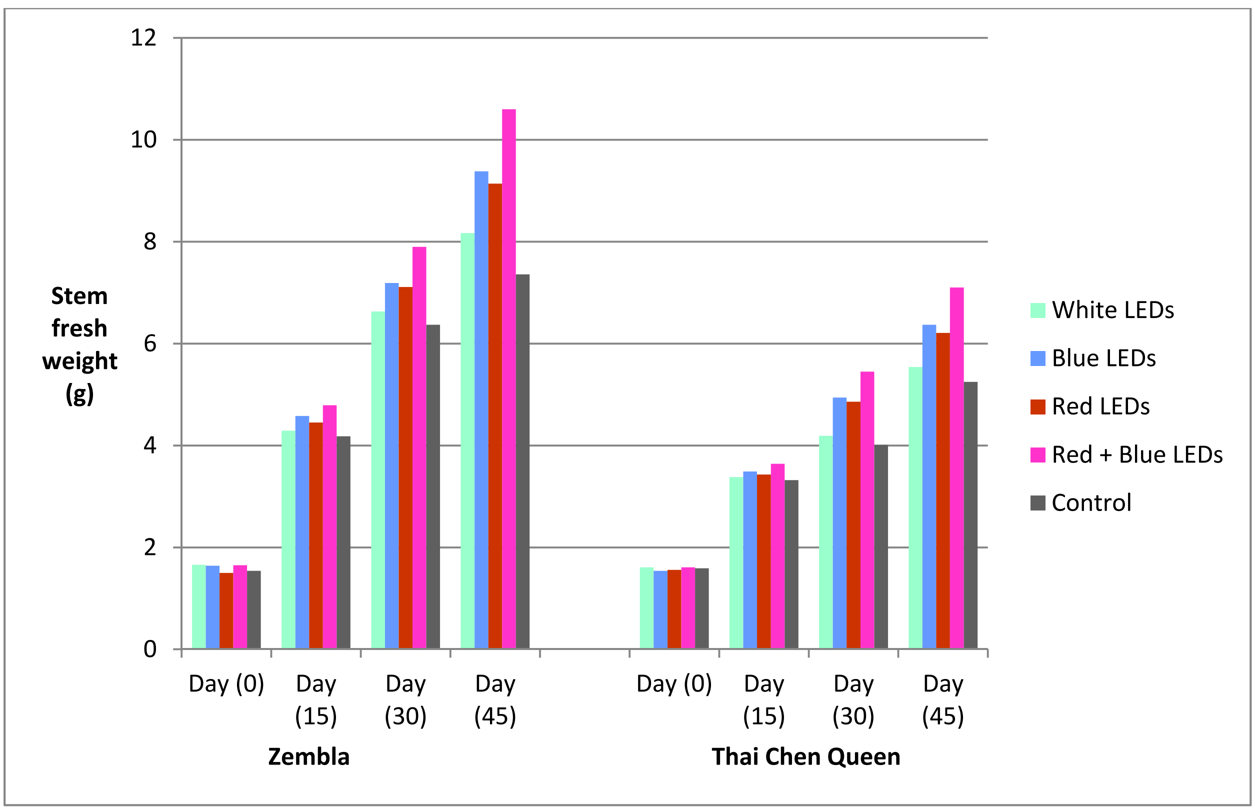


Figure 4.9 Effect of photoperiodic response on stem fresh weight in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Table 4.10 Effect of photoperiodic response on stem dry weight in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Stem dry weight (g)							
	Zembla				Thai Chen Queen			
	Day (0)	Day (15)	Day (30)	Day (45)	Day (0)	Day (15)	Day (30)	Day (45)
White	0.28	0.82 (192.9%)	1.27 (353.6%)	2.48 (785.7%)	0.29	0.63 (117.3%)	0.97 (234.5%)	1.44 (396.6%)
Blue	0.28	0.87 (210.7%)	1.44 (414.3%)	2.73 (875.0%)	0.25	0.69 (176.0%)	1.10 (340.0%)	1.54 (516.0%)
Red	0.27	0.83 (207.4%)	1.36 (403.7%)	2.61 (866.7%)	0.26	0.67 (157.7%)	1.09 (319.2%)	1.52 (484.6%)
Red + Blue	0.29	0.96 (231.0%)	1.62 (458.6%)	3.16 (989.7%)	0.28	0.80 (185.7%)	1.38 (392.8%)	1.82 (550.0%)
Control**	0.28	0.80 (185.7%)	1.26 (350.0%)	2.35 (739.3%)	0.28	0.58 (107.1%)	0.91 (225.9%)	1.32 (371.4%)
SE(m)±	0.01	0.02	0.05	0.11	0.02	0.03	0.06	0.07
C.D. $_{(0.05)}$	NS	0.07	0.15	0.35	NS	0.10	0.19	0.23

*PAR exposure @ 110 µmol m^{-2} s^{-1}; **HPS Light ; Increase in values is given in parenthese

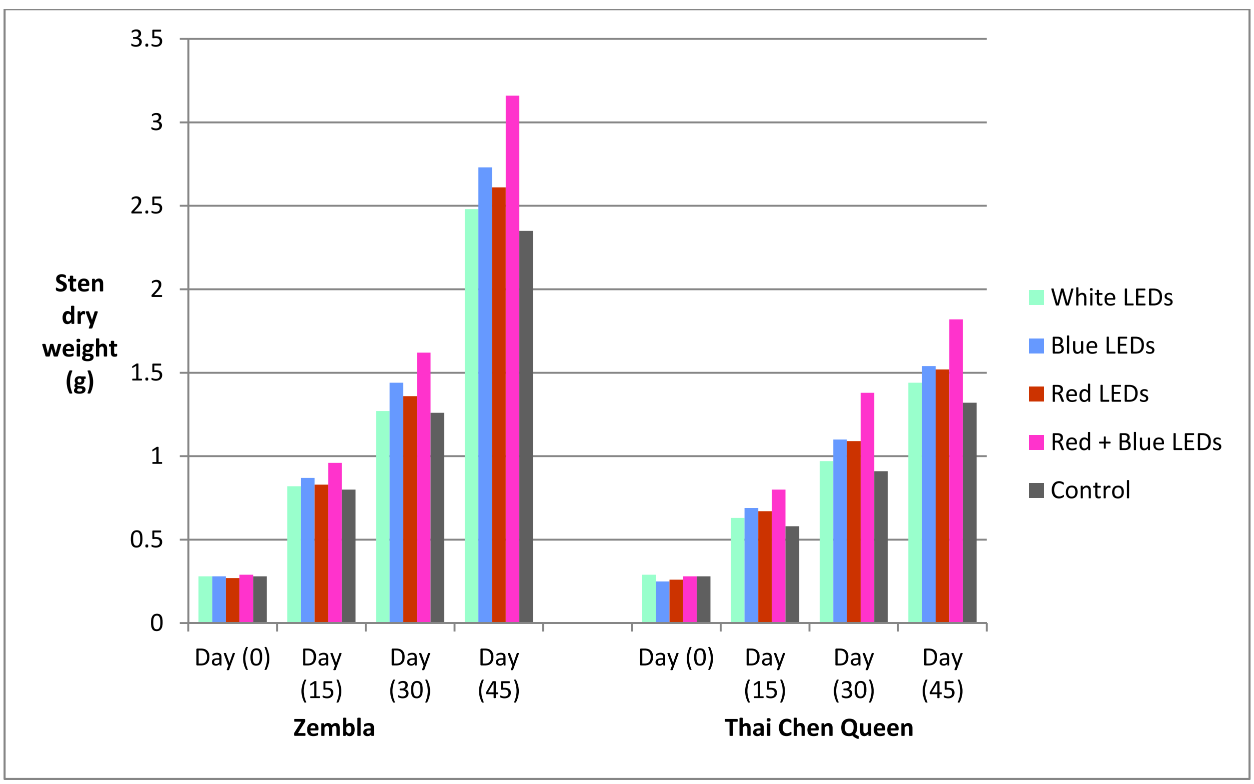


Table 4.10 Effect of photoperiodic response on stem dry weight in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

exposed with mixed Red + Blue LEDs at 45 days followed by plants illuminated with Blue LEDs (875%) at 45 days while minimum comparative percent increase was recorded under control (739.3%) in which plants were exposed with HPS light. Increase in stem dry weight in cultivar, Thai Chen Queen was recorded highest in the plants illuminated with mixed Red + Blue LEDs (550%) at 45 days followed by plants exposed to Blue LEDs (516%). Whereas, minimum per cent increase in stem dry weight was recorded in plants grown under control (107.1%) recorded 15 days and rose to 371.4% which remain lower but at par with White LEDs (396.6%).

4.1.11 Crop growth rate (g m^{-2} day^{-1})

An estimate on crop growth rate recorded for each LED treatment at 15 days interval had shown a significant difference in crop growth rate (Table 4.11 and Fig. 4.11). Crop growth rate was measured highest (10.24 g m^{-2} day^{-1}) in the plants grown under mixed Red + Blue LEDs while it was lowest (7.94 g m^{-2} day^{-1}) under control in cultivar Zembla at 45 days. Crop growth remained higher during 30 to 45 days than recorded during 0 to 15 days which showed a least gain in middle phase of 15 to 30 days in case of both the cultivars. Maximum crop growth rate was measured during 30 to 45 days highest as 10.24 g m^{-2} day^{-1} under mixed Red +Blue LEDs witnessed an additional increase by 29% than measured for the plants grown under control in Zembla. Whereas, a highest growth rate (6.60 g m^{-2} day^{-1}) was recorded from the plants grown under mixed Red + Blue LEDs which remained 26% higher than that in control during 30 to 45 days after transplanting .

4.1.12 Relative growth rate (g g^{-1} day^{-1})

Response to different light treatments was measured in terms of relative growth rate presented in Table 4.12 and Fig. 4.12. It was estimated that a maximum relative growth rate (0.028 g g^{-1} day^{-1}) was obtained from the plants grown under mixed Red + Blue LEDs while lowest (0.010 g g^{-1} day^{-1}) under the control. A significant growth rate was estimated in cultivar, Zembla at 15 days and calculated 0.028 and 0.023 g g^{-1} day^{-1} in the plants raised under mixed Red + Blue and HPS lighting (control), respectively. Whereas, cultivar Thai Chen Queen, registered significantly higher values of relative growth rate as 0.028 and 0.019 g g^{-1} day^{-1} in the plants grown under mixed Red + Blue LEDs and control, respectively and minimum values (ranging from 0.011 to 0.014 g g^{-1} day^{-1} in both the cultivars) during 30 to 45 days period of growth.

4.1.13 Net photosynthetic rate (µmol m^{-2} s^{-1})

Photosynthetic activity (Table 4.13 and Fig 4.13) in both the cultivars was measured by infra red gas analyzer (IRGA) at 0, 15, 30 and 45 days. Net photosynthetic rate was measured significantly higher in plants grown under mixed Red + Blue LEDs as compared with those under control. Values for net photosynthetic rate in cultivar, Zembla were recorded 12.28 and 7.74 µmol m^{-2} s^{-1} in plants grown under mixed Red + Blue and control, respectively at 45 days. Whereas, net photosynthetic rate were recorded 10.48 and 8.72 µmol m^{-2} s^{-1} in plants grown under Blue and Red LEDs, respectively. Similar pattern is seen and values are recorded in cultivar, Thai Chen Queen measuring a net photosynthetic rate of 13.04 and 8.38 µmol m^{-2} s^{-1} at 45 days. An increase of 58.6% and 35.4% in net photosynthetic rate in Zembla at 45 days was observed in the plants grown under mixed Red + Blue and Blue LEDs, respectively which remained at par with those obtain for plants under control. An increased net photosynthetic rate of 55.6% and 35.4% was observed in cultivar, Thai Chen Queen at 45 days under mixed Red + Blue LEDs and Blue LEDs, respectively.

4.1.14 Stomatal conductance (mmol m^{-2} s^{-1})

Stomatal conductance was recorded at 0, 15, 30 and 45 days (Table 4.14 and Fig 4.14) varied among the treated plants under different coloured LEDs but showed a non significant difference among themselves. The values of stomatal conductance were higher during initial stage of growth and varied from lowest being 0.131 to 0.136 being highest in cultivar, Zembla and 0.122 to 0.136 mmol m^{-2} s^{-1} in cultivar, Thai Chen Queen. However, stomatal conductance estimated remained maximum in the plants which were grown under an exposure with a mixed Red + Blue LEDs (0.039 and 0.044 mmol m^{-2} s^{-1}, respectively in Zembla and Thai Chen Queen), while minimum under control (0.035 and 0.037 mmol m^{-2} s^{-1}, respectively).

4.1.15 Net assimilation rate (g cm^{-2} day^{-1})

Net assimilation rate calculated and presented in the Table 4.15 and Fig 4.15. It showed a significant difference among plants grown under different treatments with LEDs. NAR recorded at 15, 30 and 45 days after treating plants under different treatments revealed that it remained maximum during early 15 days of growth and gradually decrease until period till 30 days and further decreased at 45 days in both the cultivars. NAR of plants grown under mixed Red + Blue LEDs at 15, 30 and 45 days

Table 4.11 Effect of photoperiodic response on crop growth rate in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Crop growth rate (g m^{-2} day^{-1})					
	Zembla			Thai Chen Queen		
	Day (15)	Day (30)	Day (45)	Day (15)	Day (30)	Day (45)
White	6.81	4.79	8.04	5.44	4.55	5.31
Blue	7.75	5.71	9.43	6.51	4.92	5.67
Red	7.46	5.60	9.41	6.17	4.97	5.60
Red + Blue	8.56	6.24	10.24	7.62	5.79	6.60
Control**	6.55	4.71	7.94	5.19	4.37	5.24
SE(m)±	0.27	0.24	0.29	0.26	0.18	0.21
C.D. $_{(0.05)}$	0.85	0.77	0.92	0.82	0.59	0.67

*PAR exposure @ 110 µmol m^{-2} s^{-1} ; **HPS Light

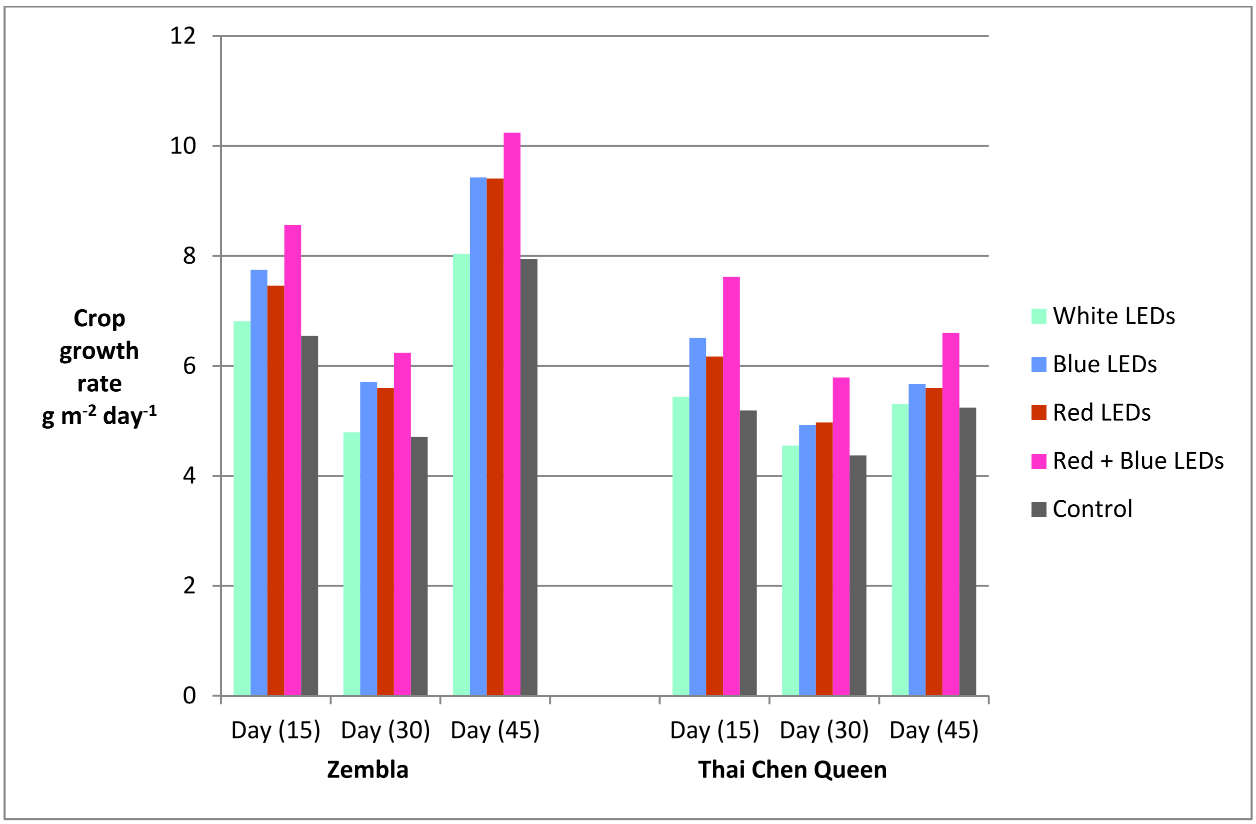


Figure 4.11 Effect of photoperiodic response on crop growth rate in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Table 4.12 Effect of photoperiodic response on relative growth rate in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Relative growth rate (g g^{-1} day^{-1})					
	Zembla			Thai Chen Queen		
	Day (15)	Day (30)	Day (45)	Day (15)	Day (30)	Day (45)
White	0.024	0.010	0.013	0.020	0.010	0.011
Blue	0.027	0.011	0.014	0.024	0.011	0.012
Red	0.026	0.010	0.014	0.023	0.011	0.011
Red + Blue	0.028	0.012	0.016	0.028	0.013	0.014
Control**	0.023	0.010	0.013	0.019	0.010	0.011
SE(m)±	0.001	0.001	0.001	0.001	0.001	0.001
C.D. $_{(0.05)}$	0.003	NS	NS	0.003	NS	0.002

*PAR exposure @ 110 µmol m^{-2} s^{-1} ; **HPS Light

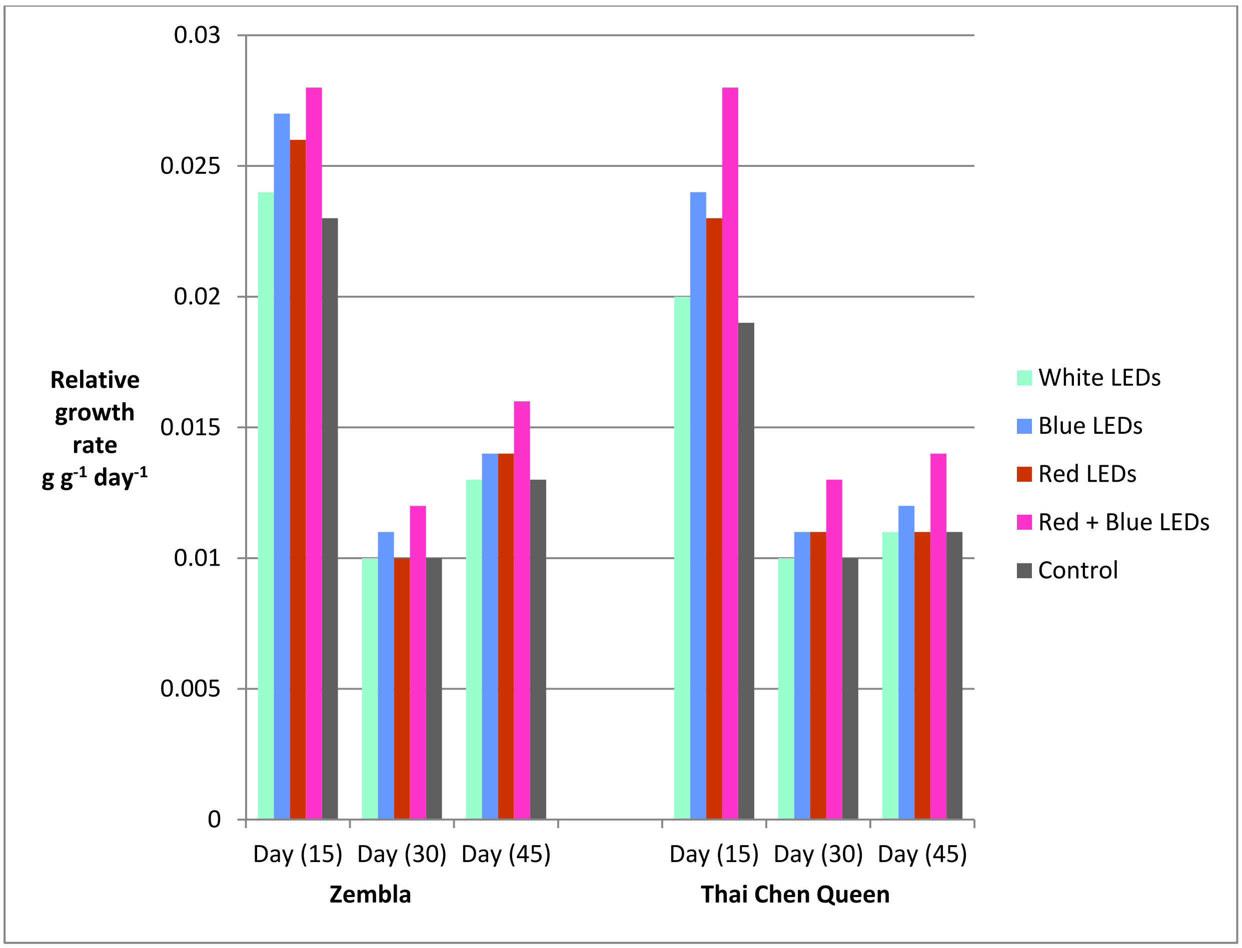


Figure 4.12 Effect of photoperiodic response on relative growth rate in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Table 4.13 Effect of photoperiodic response on net photosynthetic rate in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Net photosynthetic rate (µmol $m^{-2}s^{-1}$)							
	Zembla				Thai Chen Queen			
	Day (0)	Day (15)	Day (30)	Day (45)	Day (0)	Day (15)	Day (30)	Day (45)
White	8.86	4.68	6.86	8.01	9.80	5.05	7.19	8.64
Blue	8.95	6.46	9.01	10.48	9.65	6.92	9.56	11.35
Red	8.83	5.49	7.72	8.72	9.57	5.78	8.40	9.69
Red + Blue	8.86	7.37	10.73	12.28	9.52	8.54	11.50	13.04
Control**	8.70	4.35	6.77	7.74	9.59	4.92	6.88	8.38
SE(m)±	0.14	0.21	0.27	0.31	0.14	0.21	0.31	0.34
C.D. $_{(0.05)}$	NS	0.68	0.87	1.00	NS	0.68	0.98	1.09

*PAR exposure @ 110 µmol m^{-2} s^{-1}; **HPS Light;

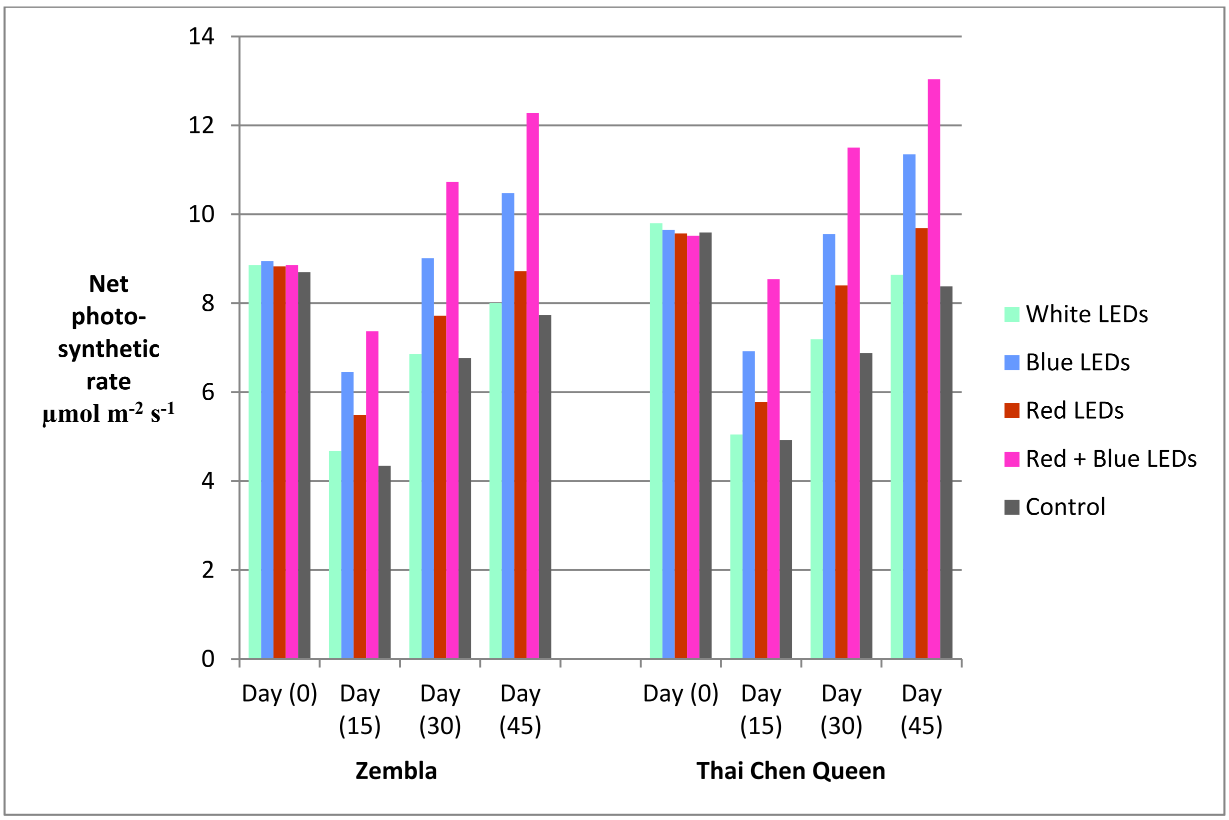


Figure 4.13 Effect of photoperiodic response on net photosynthetic rate in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Table 4.14 Effect of photoperiodic response on stomatal conductance in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Stomatal conductance (mmol m^{-2} s^{-1})							
	Zembla				Thai Chen Queen			
	Day (0)	Day (15)	Day (30)	Day (45)	Day (0)	Day (15)	Day (30)	Day (45)
White	0.133	0.022	0.035	0.041	0.122	0.020	0.027	0.038
Blue	0.131	0.023	0.037	0.045	0.136	0.020	0.031	0.041
Red	0.128	0.024	0.037	0.045	0.126	0.020	0.029	0.040
Red + Blue	0.134	0.024	0.039	0.047	0.124	0.024	0.033	0.044
Control**	0.136	0.022	0.035	0.041	0.133	0.018	0.026	0.037
SE(m)±	0.004	0.001	0.003	0.002	0.003	0.002	0.003	0.002
C.D. $_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS

*PAR exposure @ 110 µmol m^{-2} s^{-1} ; **HPS Light

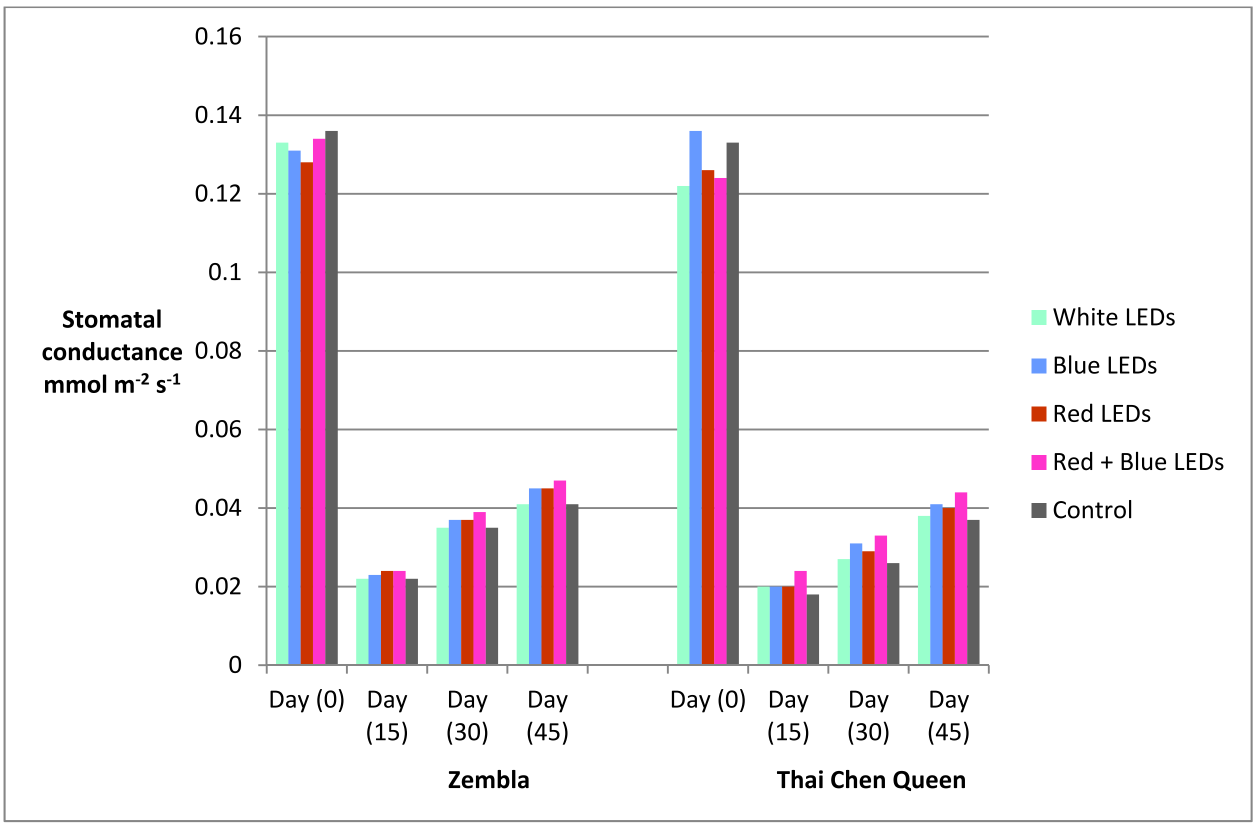


Figure 4.14 Effect of photoperiodic response on stomatal conductance in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Table 4.15 Effect of photoperiodic response on net assimilation rate in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Net assimilation rate (g cm^{-2} day^{-1})					
	Zembla			Thai Chen Queen		
	Day (15)	Day (30)	Day (45)	Day (15)	Day (30)	Day (45)
White	5.19	4.27	3.15	5.08	3.35	2.86
Blue	5.99	4.49	3.51	5.36	3.67	3.34
Red	5.63	4.45	3.45	5.18	3.45	3.31
Red + Blue	6.39	5.12	4.13	6.03	4.22	3.93
Control**	5.08	4.07	3.05	4.94	3.24	2.79
SE(m)±	0.20	0.19	0.17	0.23	0.18	0.21
C.D. (0.05)	0.63	0.61	0.53	0.72	0.59	0.68

*PAR exposure @ 110 µmol m^{-2} s^{-1} ; **HPS Light

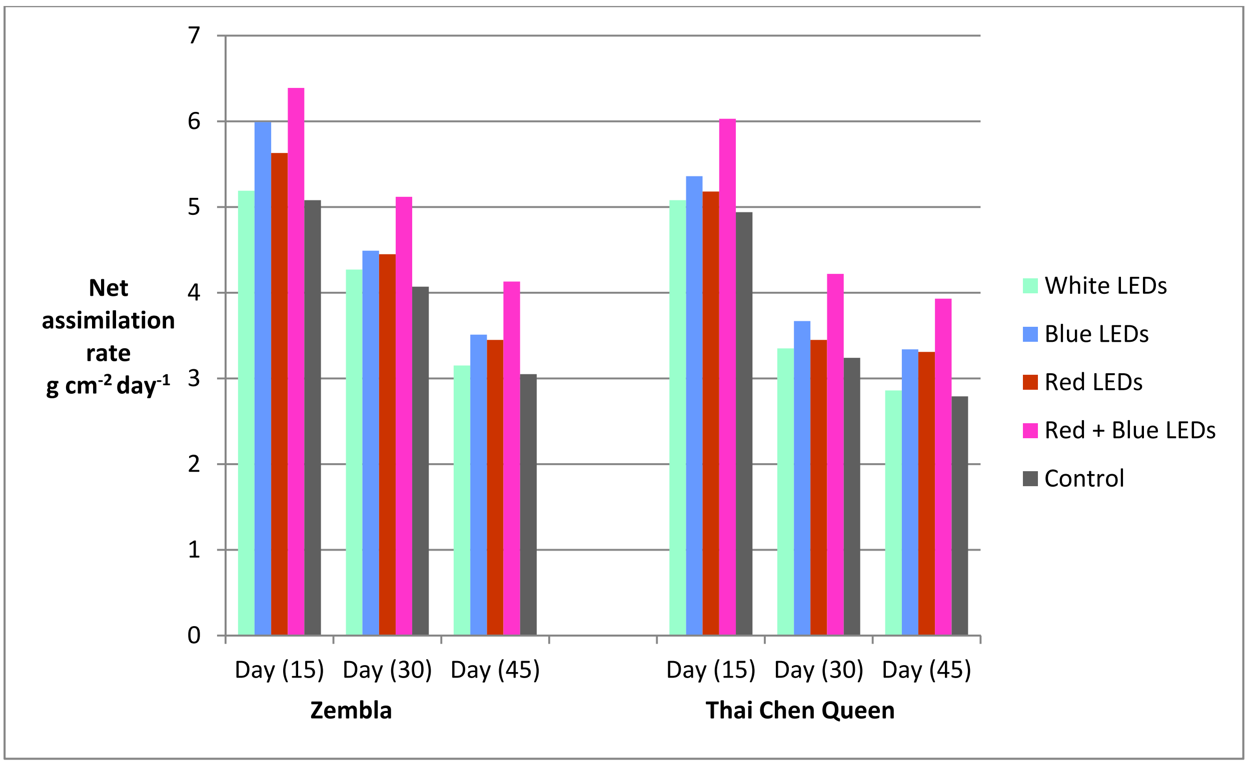


Figure 4.15 Effect of photoperiodic response on net assimilation rate in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

were recorded 6.39, 5.12 and 4.13 g cm^{-2} day^{-1}, respectively in cultivar, Zembla which remained higher than the plants raised under control and recorded 5.08, 4.07 and 3.05 g cm^{-2} day^{-1} respectively at 15, 30 and 45 days. Similar values (6.03, 4.22 and 3.93 g cm^{-2} day^{-1}) of NAR were recorded for Thai Chen Queen at 15, 30 and 45 days in the plants kept under mixed Red + Blue LEDs which were 22.06, 30.2 and 40.8% higher than those in plants under control.

4.2 Objective II.

To study the response of different coloured LEDs on induction and quality of flowers in chrysanthemum.

4.2.1 Time taken for flower bud induction (days)

Time taken for bud induction varied among the different light treatments (Table 4.16 and Fig 4.16). In cultivar, Zembla flower bud appeared at the earliest (42.53 days) under the Blue coloured LEDs while it was delayed by 48.17 days under the control. An early flower bud induction was observed in the plants raised under an admixture of Red + Blue LEDs (44.07 days), while it further delayed under White LEDs. Whereas in cultivar, Thai Chen Queen, Blue LEDs resulted in early flower bud initiation (45.60 days) which was further delayed by 52.23 days under control. Under mixture of Red + Blue LEDs, bud induction also started early (47.33 days) while it got delayed under White LEDs (51.80 days). An early bud induction was recorded in both the cultivars under Blue coloured LEDs and took 6-7 days less as compare to time taken under control. Under mixed Red + Blue LEDs, the bud induction took place 3 days after the bud induction in the plants through Blue LEDs.

4.2.2 Time taken for flower opening (days)

A variation was estimated for flower opening under the different treatment with LEDs (Table 4.16 and Fig. 4.17) in cultivars, Zembla and Thai Chen Queen and took 52.10 and 55.10 days (earliest) respectively under Blue LEDs while delayed by single day under mixed Red + Blue LEDs. Flower opening under mixed Red + Blue LEDs took place 1-2 days after flowering in the plants raised under Blue LEDs. In Zembla, flower opening was delayed by 6.7 days under control and by 6.3 days under White LEDs which was further delayed in control than under Blue LEDs. There was an early flowering in Thai Chen Queen, under Blue LEDs by 8.03 and 6.13 days compared with control and white LEDs, respectively.

4.2.3 Bud diameter (mm)

Data recorded on bud diameter varied significantly among plants grown under different treatments of light (Table 4.16 and Fig. 4.18). Red + Blue coloured LEDs had produced maximum bud diameter (7.40 and 8.30 mm) in Zembla and Thai Chen Queen and minimum under control and White LEDs. Which showed an increase of 13% and 12.3% in plants exposed with Red + Blue LEDs as compare to control and White LEDs, respectively. Whereas, Thai Chen Queen cultivar produced an increased (12.6% and 12%) bud diameter in plants with Red + Blue LEDs as compare to control and White LEDs, respectively.

4.2.4 Flower diameter (cm)

Observations recorded for flower opening varied significantly among the different treatments of light (Table 4.16 and Fig. 4.19). A maximum flower diameter was recorded under mixed Red + Blue LEDs where 11.67 and 12.63 cm recorded in Zembla and Thai Chen Queen, respectively. A minimum flower diameter was recorded under control (10.07 and 11.33 cm, respectively). Flower diameter in cultivar, Zembla registered an increase in flower diameter by 15.9% as compare with control whereas under the same condition flower diameter increased by 11.5% in Thai Chen Queen. However, the other effects were noted non significant in cultivars, Zembla and Thai Chen Queen under Red + Blue LEDs and remain at par with control.

4.2.5 Cut flower stem length (cm)

A significant increase in cut flower stem length was recorded under different treatments of light (Table 4.17, Fig. 4.20; Plate 4.1, 4.2). Maximum cut flower stem length (68.13 cm) was recorded in Zembla under Blue LEDs followed by mixed Red + Blue LEDs (64.50 cm) while minimum stem length was recorded under Red LEDs (55.10 cm). Similar pattern was observed in Thai Chen Queen where 46.50, 43.50 and 35.07 cm cut stem lengths were recorded under Blue, mixed Red + Blue and Red LEDs, respectively. In Zembla, an increase of 23.6% and 17.1% cut stem length was obtained under Blue LEDs and mixed Red + Blue LEDs respectively as compare to Red LEDs while 14.7% and 8.6% cut flower stem length was recorded under Blue LEDs and mixed Red + Blue LEDs as compare with control. Whereas, in Thai Chen Queen

Table 4.16 Effect of photoperiodic response on time taken for flower bud induction, time taken for flower opening, bud diameter and flower diameter in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Time taken for flower bud induction (days)		Time taken for flower opening (days)		Bud diameter (mm)		Flower diameter (cm)	
	Zembla	Thai Chen Queen	Zembla	Thai Chen Queen	Zembla	Thai Chen Queen	Zembla	Thai Chen Queen
White	47.77	51.80	58.40	61.23	6.59	7.41	10.33	11.63
Blue	42.53	45.60	52.10	55.10	6.79	7.64	10.83	11.93
Red	45.43	48.77	55.83	59.20	6.80	7.62	10.70	12.07
Red + Blue	44.07	47.33	53.93	56.50	7.40	8.30	11.67	12.63
Control**	48.17	52.23	58.80	63.13	6.55	7.37	10.07	11.33
SE(m)±	0.33	0.21	0.25	0.22	0.06	0.06	0.10	0.08
C.D. (0.05)	1.05	0.67	0.80	0.71	0.21	0.20	0.33	0.27

*PAR exposure @ 110 µmol m^{-2} s^{-1} ; **HPS Light

Table 4.17 Effect of photoperiodic response cut flower stem length, flower fresh weight and flower dry weight in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

Treatment with LEDs*	Cut flower stem length (cm)		Flower fresh weight (g)		Flower dry weight (g)	
	Zembla	Thai Chen Queen	Zembla	Thai Chen Queen	Zembla	Thai Chen Queen
White	59.47	38.77	14.17	15.33	1.64	1.53
Blue	68.13	46.50	16.80	17.60	1.71	1.62
Red	55.10	35.07	16.40	17.23	1.74	1.64
Red + Blue	64.50	43.50	17.67	18.77	1.89	1.78
Control**	59.40	38.50	14.13	15.03	1.61	1.50
SE(m)±	0.82	0.78	0.19	0.12	0.04	0.02
C.D. (0.05)	2.63	2.49	0.38	0.39	0.12	0.06

*PAR exposure @ 110µmol m^{-2} s^{-1} ; **HPS Light

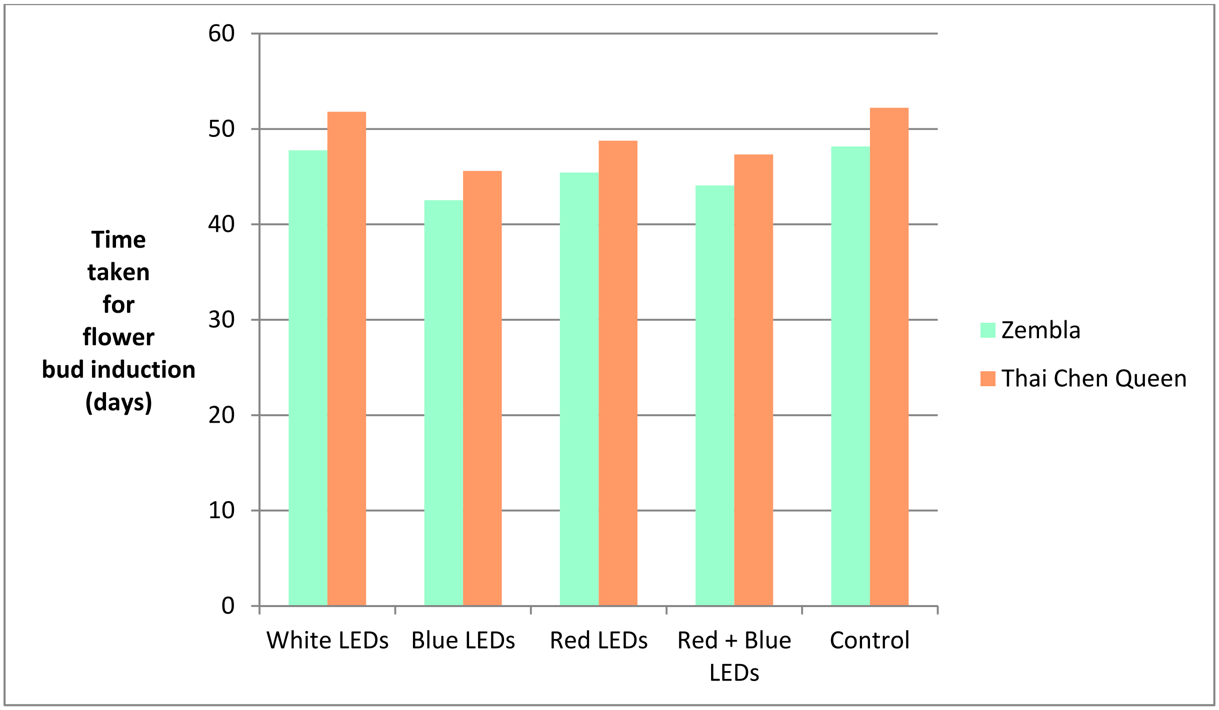


Figure 4.16 Effect of photoperiodic response on time taken for flower bud induction in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

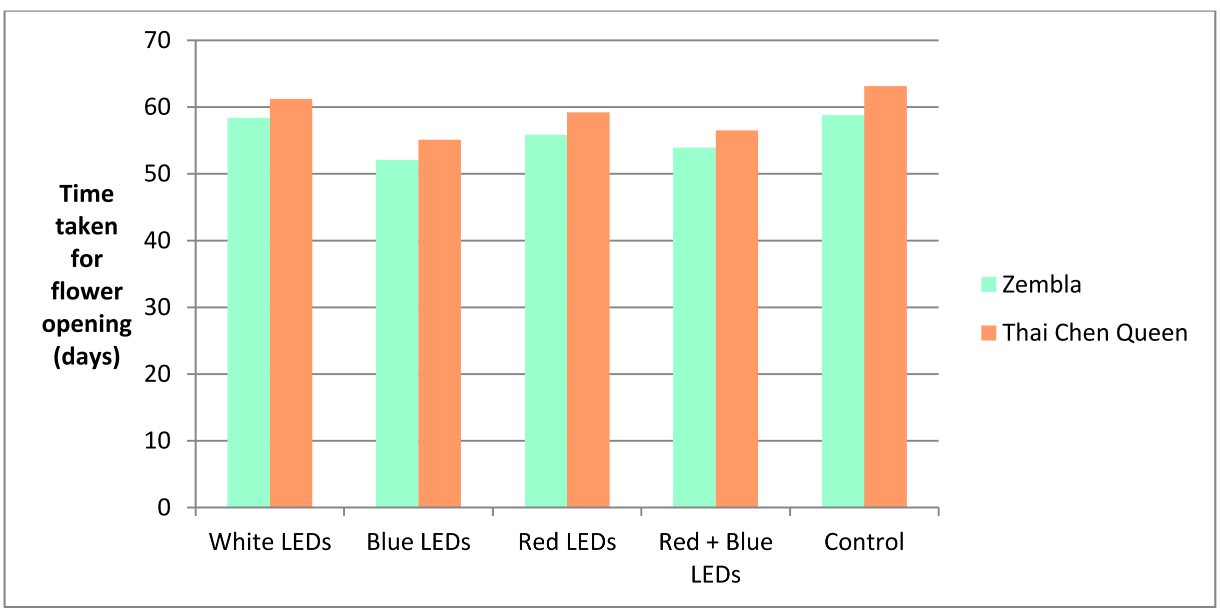


Figure 4.17 Effect of photoperiodic response on time taken for flower opening in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

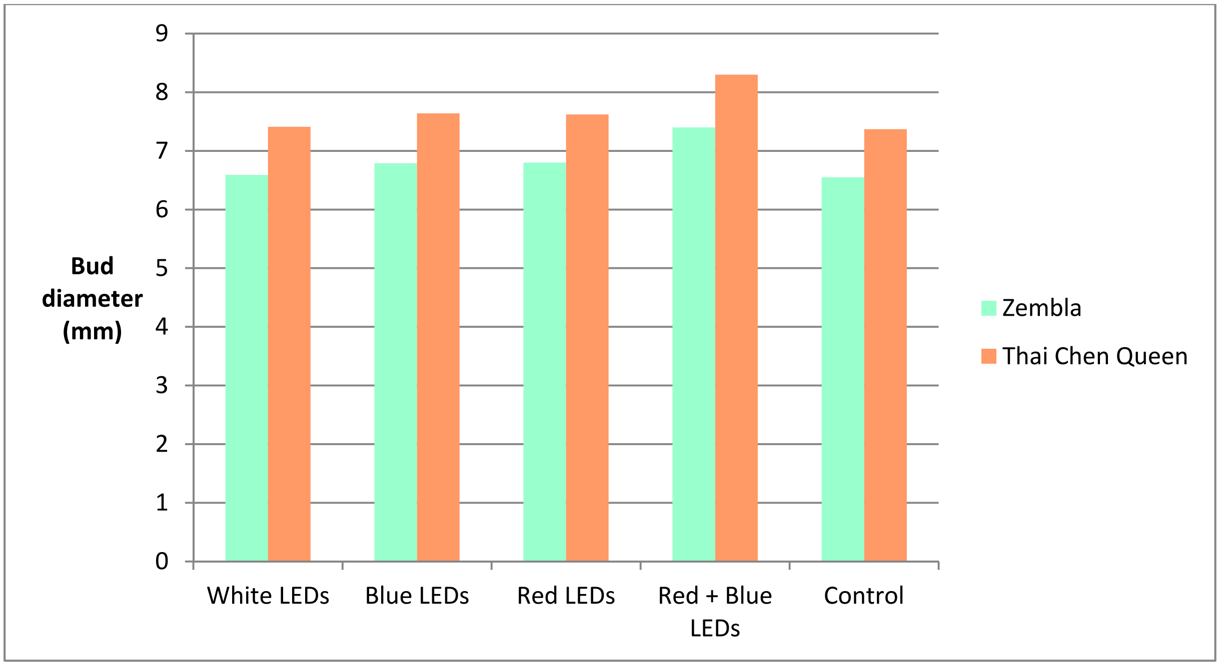


Figure 4.18 Effect of photoperiodic response on bud diameter (mm) in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

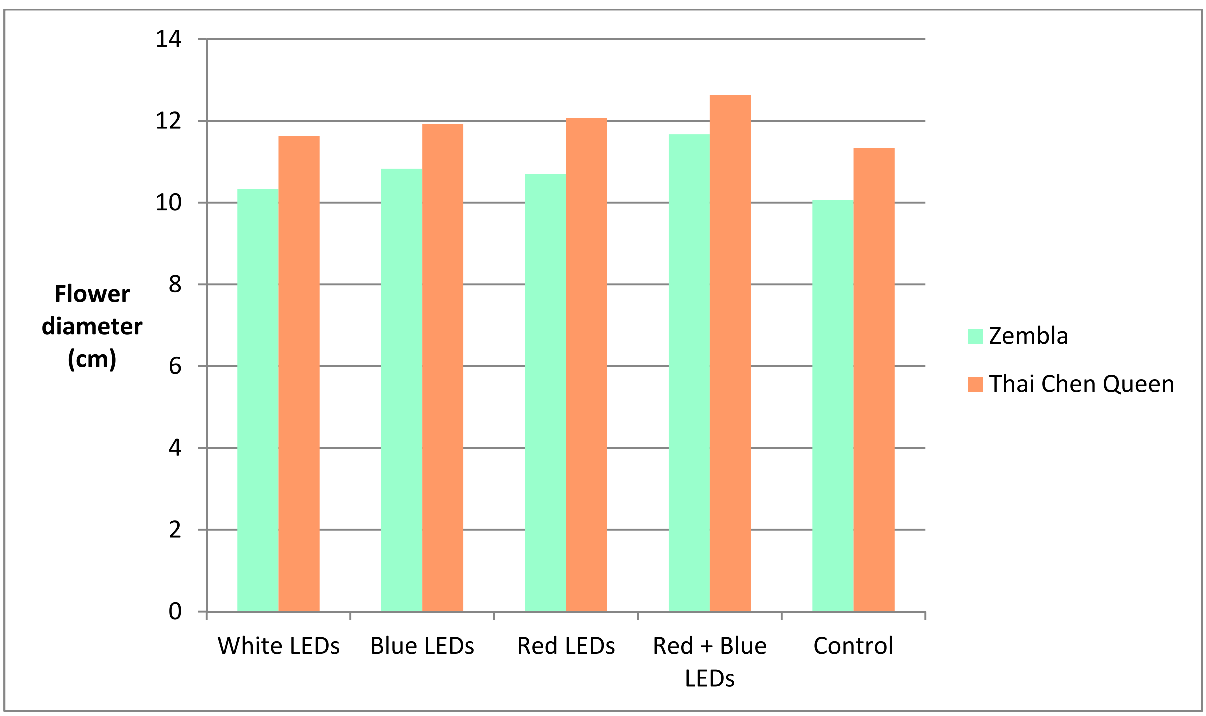


Figure 4.19 Effect of photoperiodic response on flower diameter (cm) in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

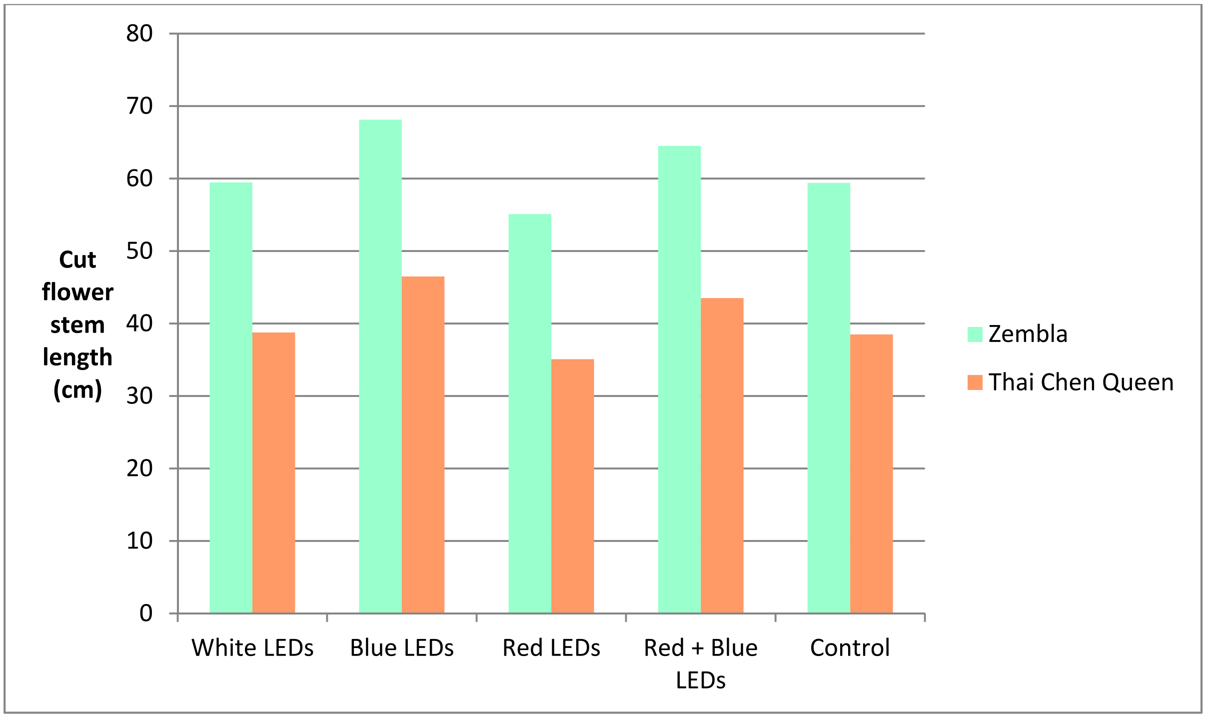


Figure 4.20 Effect of photoperiodic response on cut flower stem length (cm) in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

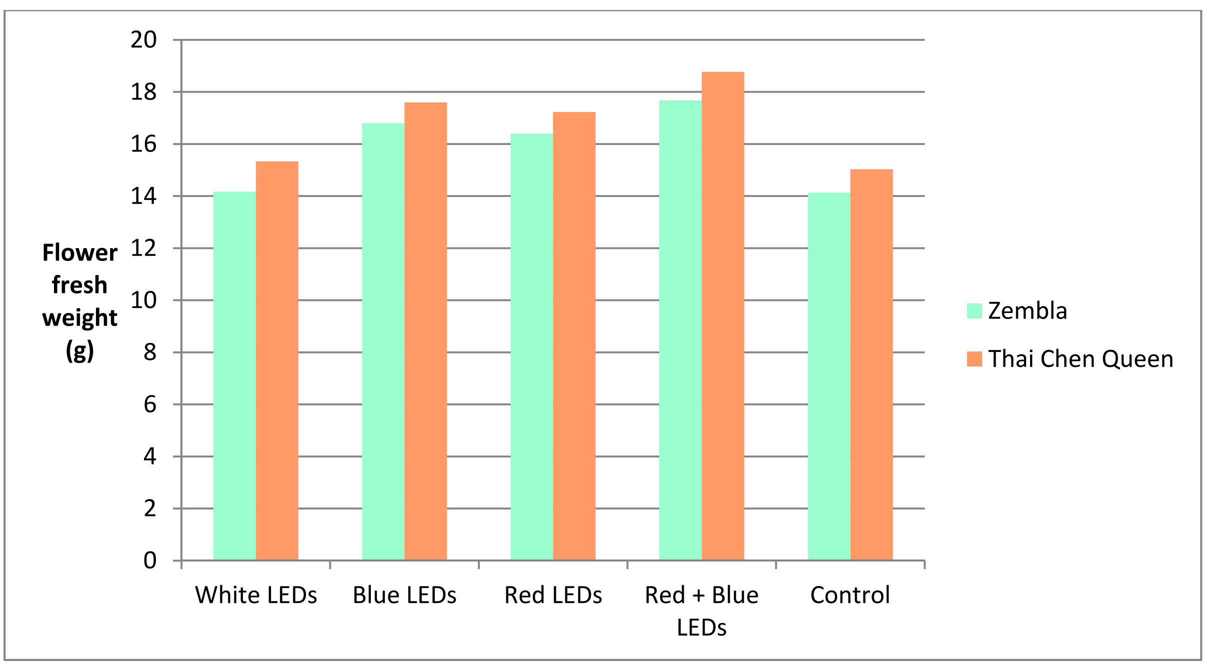


Figure 4.21 Effect of photoperiodic response on flower fresh weight (g) in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

cultivar, 32.6 and 24% increase in cut flower stem length was observed under Blue (46.50 cm) and mixed Red + Blue LEDs (43.50 cm) as compare to Red LEDs (35.07 cm) and control, Blue and mixed Red + Blue LEDs enhanced 20.8 and 13% cut flower stem length, respectively.

4.2.6 Flower fresh weight (g)

Flower fresh weight varied among different treatment (Table 4.17 and Fig. 4.21) of light and remained highest (17.67 and 18.77g) under mixed Red + Blue LEDs in both of the cultivars, respectively. Both the cultivars grown under mixed Red + Blue LEDs approximately 25% more fresh weight was recorded as compare to control. Under Blue and Red coloured LEDs flower fresh weight was significantly higher than control and White LEDs which was non-significant.

4.2.7 Flower dry weight (g)

A significant variation was estimated for flower dry weight under different treatment of LEDs (Table 4.17 and Fig. 4.22). In cultivar, Zembla maximum flower dry weight was recorded under mixed Red + Blue LEDs (1.89g), while minimum flower dry weight was observed under control (1.61g). Similar values were noted in Thai Chen Queen (1.78g) under mixed Red + Blue LEDs and 1.50g dry weight measured under control. An increase of 17.4% and 18.7% in flower dry weight was observed under mixed Red + Blue LEDs in Zembla and Thai Chen Queen, respectively as compare with control.

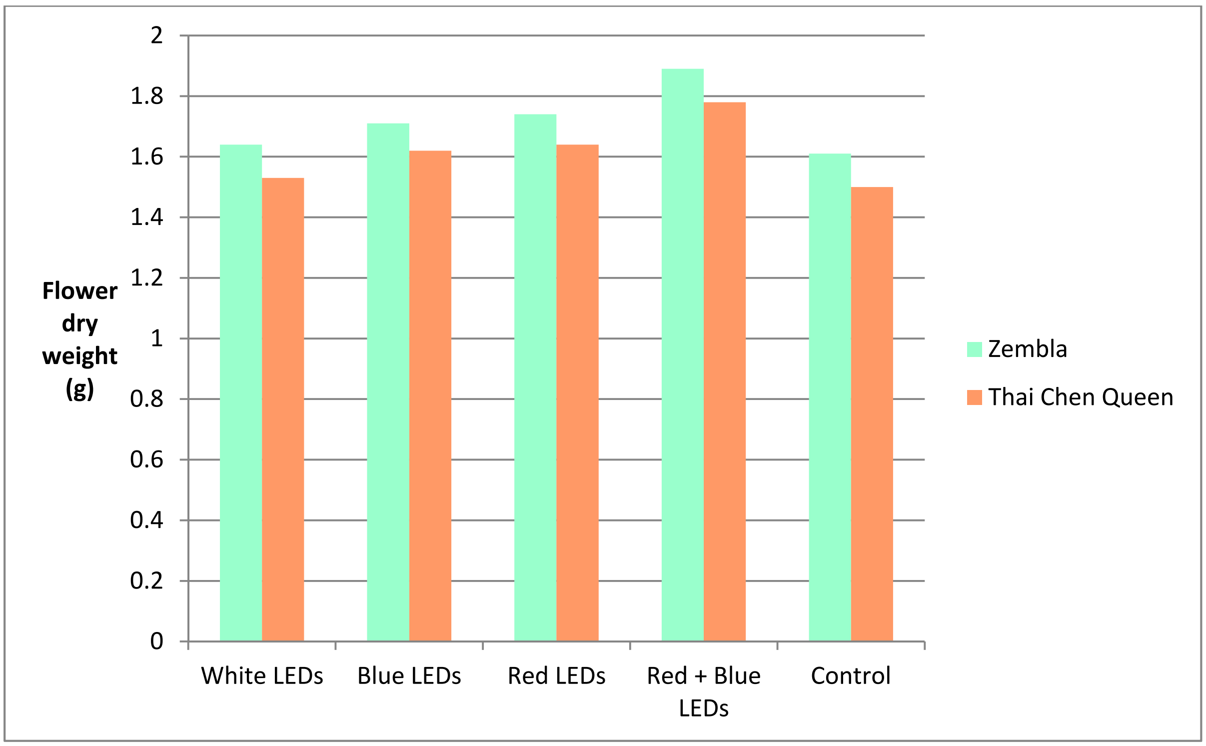
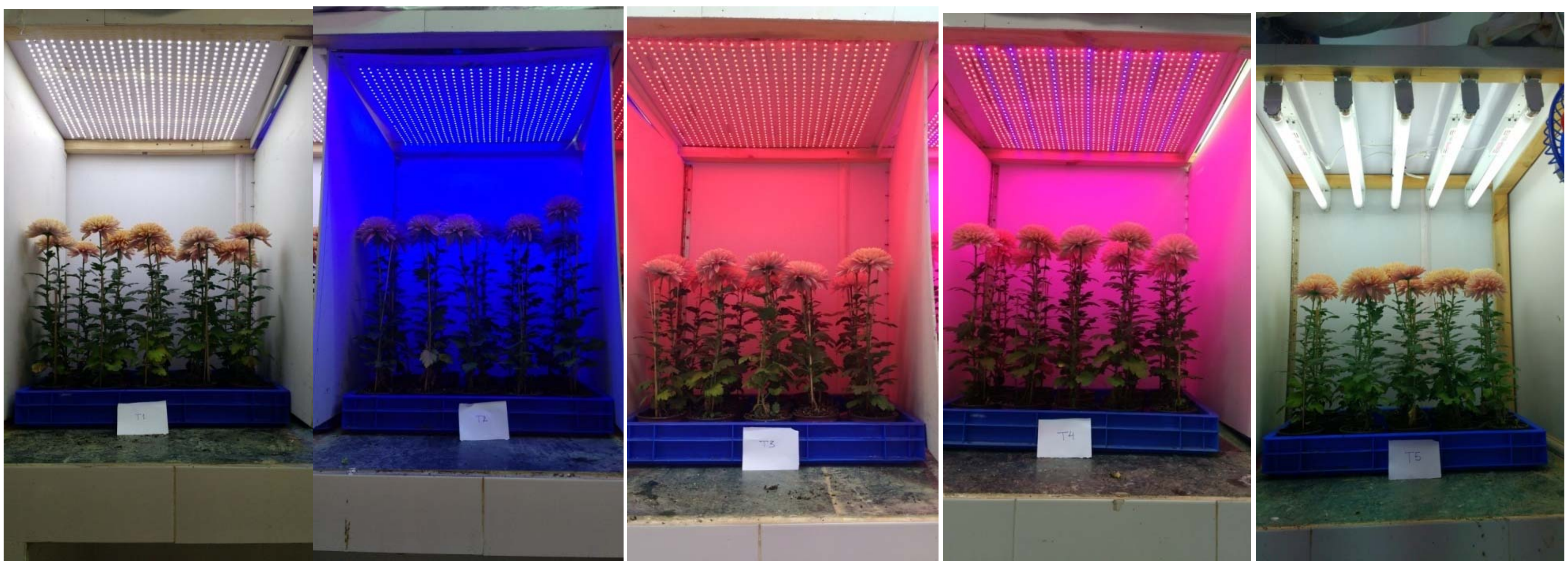


Figure 4.22 Effect of photoperiodic response on flower dry weight (g) in *Chrysanthemum morifolium* Ramat. cvs. Zembla and Thai Chen Queen.

T_1 White LEDs | T_2 Blue LEDs | T_3 Red LEDs | T_4 R80% + B 20% LEDs | T_5 Control

Plate 4.1 Flowering in *Chrysanthemum morifolium* Ramat. cv. Zembla under different light treatments



T$_1$ White LEDs **T$_2$ Blue LEDs** **T $_3$ Red LEDs** **T$_4$ R80% + B 20% LEDs** **T$_5$ Control**

Plate 4.2 Flowering in *Chrysanthemum morifolium* Ramat. cv. Thai Chen Queen under different light treatments

Chapter 5

DISCUSSION

In the present investigation entitled "Studies on photoperiodic response in *Chrysanthemum morifolium* Ramat." was conducted under different coloured LEDs to substantiate the effect of day length extension using photo-synthetically active radiation and a long day photoperiod through HPS lighting was estimated on vegetative growth and flowering. *Chrysanthemum* is a short day plant which requires short days for flowering provided through covering the greenhouse by black polythene or white wash of roof under warmer climate to enable the possibilities of round the year cultivation. However, under North-Indian conditions due to sudden change in weather and decreased day length *Chrysanthemum* tends to initiate flowering without attaining the sufficient vegetative growth and dry matter to produce a quality flower. It is essential to produce sufficient stem length and quality cut flowers, plants are exposed to long days for a period of several weeks followed by short day period. To resolve whether the *Chrysanthemum* would flower under long days by providing light through smart LEDs as photo-synthetically active radiation (PAR). In winter months, when available natural day length is shorter, supplemental light is provided through artificial source to achieve adequate vegetative growth while in summer, the day length can be cut either by covering the plants by black polythene sheets or a roof white wash to create artificial short day conditions (Horridge *et al.,* 1984).

It is established that *Chrysanthemum* is a light sensitive plant where a signal for flower bud initiation is generated from phytochrome reaction from leaves to initiation of flower primordial tissue. Flower bud induction is normal in chrysanthemum even under long days by providing light through smart LEDs as PAR without disturbing the short days (Singh *et al.*, 2013). Hence, in the present study different coloured LEDs were used to provide light as long days (15h), to understand that which light spectrum and source of light would produce quality flowers and prove best for vegetative growth as well as bud induction and flowering. The results thus obtained in the previous chapter are being discussed as following.

Light works as an environmental signal in chrysanthemum, its quality and quantity has a most prominent effect on growth and flowering. In the present research conducted, plants of cultivar, Zembla exhibited an increase in plant height by 17.9% under Blue LEDs over the plants under control (HPS lighting) which was 11.8% higher in plants exposed with an admixture of Red + Blue LEDs. However, the plants of cultivar, Thai Chen Queen showed 27.2% increase in plant height under Blue LEDs and 18.8% under mixed Red + Blue LEDs as compare to the plants under control. Plants grown under Red LEDs were found shortest in height. A significant increase in stem diameter was observed in both the cultivars by exposing different coloured LEDs at 45th days after keeping the plants in growth chamber. Maximum stem diameter was recorded under red LEDs followed by mixed Red + Blue LEDs while under the Blue LEDs minimum plant diameter was noted.

Heo *et al.* (2002) reported that stem length in marigold was highest in monochromic Blue light, being three times higher than in FLR or FL treatments. In salvia, FLFr increased the stem length, but this value significantly decreased in Red as compared to other treatments. This difference in response may be due to a different synergistic interaction of the Blue light receptor and phytochrome on promotion or inhibition of stem elongation. Chee (1986) reported greater shoot production rate under blue light conditions in the *Vitis* hybrid 'Remaily Seedless'. In the present study, shoot and internode length, and shoot and leaf number were always greater than those obtained under Blue LEDs. It seems that, stem elongation can be promoted or inhibited by different synergistic interactions between Blue/Red light receptors and phytochrome according to species (Kim *et al.,* 2004). Hirai *et al.* (2006) also reported a similar response of Blue light on stem growth in eggplant, while the rate of stem elongation was remarkably smaller under other monochromatic lights. Li *et al.* (2010) found that stem length of upland cotton plantlets *in-vitro* was greatest when cultured under B:R = 1:1 LED light, and lowest under fluorescent lamp. Kim *et al.* (2004) observed that stem elongation could be promoted or inhibited by different synergistic interactions between Blue or Red light receptors and phytochrome according to species. Similar response of stem elongation to light obtained from our experiments seemed to be correlated with plant species/cultivars.

The longest internodal length was recorded in the plants exposed to Blue LEDs followed by mixed Red + Blue while minimum internodal distance was observed in plant raised under Red LEDs at 45 days in both the cultivars. Number of leaves per plant showed non-significant differences among different treatments with LEDs at 15^{th} and 30^{th} days except at 45 days after planting but highest number of leaves were recorded under exposure to Blue LEDs while remained minimum under Red LEDs. Jeong *et al.* (2014) supplemental Blue light was shown to promote internode extension in the cut chrysanthemum cultivar, Zembla. This indicate that supplemental monochromatic Blue lighting for 4 h after 11 h of mixed RB light promotes internode extension, but does not interrupt flower bud formation. Supplemental B light irradiance, at least in part, may reduce the number of LDs required to obtain sufficient stem length during SD induction. Macedo *et al.,* 2011 found that Number of leaves/plant were significantly increased in *Alternanthera brasiliana* plants grown under Blue fluorescent light as compared with White and Red fluorescent light. These results obtained are in close agreement with our findings.

Leaf area is an important trait to assess the effect of light and it was noted that in both cultivars, a maximum leaf area was recorded under mixed Red + Blue LEDs while minimum was estimated under control. An increase leaf area was recorded in cvs. Zembla and Thai Chen Queen by 14 and 12% respectively as compare with control noted at 45 days after, the plants were kept in mixed Red + Blue LEDs under growth chamber. Similar effects on leaf area are also reported by Macedo *et al.* (2011) in *Alternanthera brasiliana,* where Blue light induced the maximum leaf area while Green and Red lights resulted in smallest leaf areas. In *in-vitro* chrysanthemum plantlets, leaf area and chlorophyll content were greatest under a mix of Red and Blue light (RB) as reported by Jeong *et al.* (2014). Ouzounis *et al.* (2014) also found that in chrysanthemums and campanulas, the 20%B + 80%R showed highest leaf area expansion and lowest under Red and Blue lights, separately.

Maximum leaf area index was recorded from the plants raise under mixed Red + Blue followed by Blue coloured LEDs while minimum leaf area index was estimated under control. The results obtained in the present study revealed that leaf fresh and dry weight were recorded highest in the plants exposed with mixed Red + Blue LEDs followed by Blue, Red and lowest being in plants grown under HPS lighting (control) at

45 days in both the cultivars, Zembla and Thai Chen Queen. Maximum stem fresh and dry weight was recorded when grown under mixed Red + Blue LEDs and minimum stem fresh weight in plants under control at 45 days. Zembla showed an increase in stem fresh weight by 44% over control when grown under mixed Red + Blue LEDs. Whereas, Thai Chen Queen recorded an increase stem fresh weight by 35.2% than in control. Percent stem dry weight increase shown by Zembla (34.5%) and Thai Chen Queen (37.8%) under mixed Red + Blue LEDs remained at par with control which was significantly higher than under Red and Blue LEDs, separately as compared with the plants raised under HPS lighting (control). Similar results are also estimated by Shin *et al.* (2008) working in *in-vitro Doritaenopsis* plants and showed that leaf area, leaf fresh and dry weight were highest with plants grown under mixed Red + Blue LEDs. Reason being, the carbohydrate and leaf pigment biosynthesis of plants was highest in plants grown under mixed Red + Blue LEDs compare with monochromic light (Red or Blue LEDs) and fluorescent treatments. Tanaka *et al.* (1998) also reported an increase in fresh and dry weight of *Cymbidium* plantlets under RB and/or FL. Kim *et al.* (2004) could also found an increases in fresh weight, dry weight under a mixture of Red + Blue light (RB) and a fluorescent lamp (FL).

These results might be due the highest acclimation of light sourced from Blue and Red spectra, resulting from the maximum absorption peaks. Our results also showed a close proximity with the findings of Hirai *et al.* (2006) that top and dry weight of leaf-lettuce was greater under Blue and Blue-Green light, and were the smallest under Red light. In *in-vitro* chrysanthemum plantlets, increases of fresh weight and dry weight, under a mix of Red and Blue light (RB) reported by Jeong *et al.* (2014). Ouzounis *et al.* (2014) also found that in chrysanthemums, total fresh and dry weight was higher with increasing blue ratio. In lettuce, increase in blue light fraction, increased the final leaf area and dry mass reported by Yorio *et al.* (2001). Li *et al.,* 2010 could found that Blue and Red (B:R = 1:1) LED light is suitable for the increase of fresh weight and dry weight. Red LED light is effective for root growth, and Blue LED light is important for chlorophyll synthesis and stomata development of upland cotton plantlets. Lin *et al.* (2011) found that, 33% Red + 67% Blue LEDs blue LEDs promote the number of shoots, chlorophyll production and improve shoot production and the quality of shoots as compare with monochromatic Red LEDs and monochromatic Blue LEDs of *Dendrobium officinale* in vitro owing to the fact that fresh and dry mater more efficiently fixed under an exposure Blue PAR sourced from smart LEDs without disturbing the dark period in chrysanthemum as reported by Singh *et al*. (2013).

It was observed that the crop growth remained higher during 30 to 45 days than recorded during 0 to 15 days which showed a least gain in middle phase of 15 to 30 days in case of both the cultivars. Maximum crop growth rate was measured during 30-45 days highest under mixed Red + Blue LEDs witnessed an additional increase by 29% than measured for the plants grown under control in Zembla and 26% higher in Thai Chen Queen. It was estimated that a maximum relative growth rate was obtained from the plants grown under mixed Red + Blue LEDs while lowest under the control. Net photosynthetic rate was measured significantly higher in plants grown under mixed Red + Blue LEDs as compared with those under control. This might be resulted through higher rate of photosynthesis under an exposure of mixed Red + Blue LEDs. Similar effects were also observed by Nhut *et al.* (2003) and best growth of strawberry plantlets grown *in-vitro* was recorded under LED-based lighting with 70% Red and 30% Blue coloured light.

An efficient increase of 58.6% and 35.4% in net photosynthetic rate in Zembla at 45 days was observed in the plants grown under mixed Red + Blue and Blue LEDs, respectively which remained at par with those obtain for plants under control. However, an increase in net photosynthetic rate of 55.6% and 35.4% was observed in cultivar, Thai Chen Queen under mixed Red + Blue and Blue LEDs, respectively. Similar findings are also reported by Goins *et al.* (1997) and they found that that RB enhances plant growth and development by increasing net photosynthetic rate because the spectral energy distribution of RB consisted with that of chlorophyll absorption. Kim *et al.* (2004) also studied that net photosynthetic rate was consistent with plantlet growth, showing highest rate in RB followed by FL and lowest rate in B and BFr. Plantlets under RB where the growth was greatest. This could be as due to LEDs, there are peak emissions of the blue and red LEDs which coincide closely with the absorption peaks of chlorophylls and the reported wavelength of maximum photosynthetic efficiency (McCree, 1972). In contrary to this, Matsuda *et al.* (2004) found a lower photosynthetic rate for rice grown under Red LEDs alone than for plants grown under a mixture of Red + Blue LEDs.

Stomatal conductance varied among the treated plants under different coloured LEDs but showed a non-significant difference among themselves. The values of stomatal conductance were higher during initial stage of growth and lower at later stages. In this study, stomatal conductance increased under mixed Red + Blue LEDs, which suggests that decreased stomatal conductance was a contributing factor to lower photosynthetic rates under Red LEDs. It has also been suggested that the narrow peak emission of Red LEDs leads to an imbalance of photons available to photosystem-I and photosystem-II, thus altering the ratio of cyclic pattern to whole chain electron transport, and causing a reduction in net photosynthesis as reported by Tennessen *et al.* (1994). Present investigation revealed that net assimilation rate (NAR) recorded at 15, 30 and 45 days after treating plants under different treatments remained maximum during early 15 days of growth and gradually decreased until period till 30 days and further decreased till 45 days in both the cultivars. NAR of plants grown under mixed Red + Blue LEDs was recorded highest and lowest under control. These results are in close agreement with the findings reported by Jeong *et al.* (2014), in *in-vitro* chrysanthemum plantlets and found that net assimilation rate increased rapidly under mixed Red + Blue light, whereas it lowers under Blue light.

An early bud induction was recorded in both the cultivars under Blue coloured LEDs and took 6-7 days less as compare to time taken under control. Under mixed Red + Blue LEDs, the bud induction took place 3 days after the bud induction in the plants through Blue LEDs. In Zembla, flower opening was delayed by 6.7 days under control and by 6.3 days under White LEDs which was further delayed in control than under Blue LEDs. There was an early flowering in Thai Chen Queen, under Blue LEDs by 8.03 and 6.13 days compared with control and White LEDs, respectively. An increase of 13% and 12.6% in bud diameter under Red +Blue LEDs as compare to control in Zembla and Thai Chen Queen, respectively. Flower diameter in cultivar, Zembla registered an increase in flower diameter by 15.9% as compare with control whereas under the same condition flower diameter increased by 11.5% in Thai Chen Queen. Maximum cut flower stem length was recorded under Blue LEDs followed by mixed Red + Blue LEDs while minimum cut flower stem length was recorded under Red LEDs. In Zembla, 14.7% and 8.6% cut flower stem length was recorded under Blue and mixed Red + Blue as compare with control while in Thai Chen Queen Blue and mixed Red + Blue LEDs enhanced 20.8% and 13% cut flower stem length as compare with control. Both the cultivars grown under mixed Red + Blue LEDs approximately 25% more fresh weight was recorded as compare to control. An increase of 17.4% and 18.7% in flower dry weight was observed under mixed Red + Blue LEDs in Zembla and Thai Chen Queen, respectively as compare with control. Our results, are easily correlated with findings of Bangnall *et al.* (1996) where the absorption of Blue light accelerated the flowering in *Arabidopsis* and significantly reduced time of flowering in *Chrysanthemum* with the increased levels of Blue light as reported by Khattak and Pearson (1996).

Similar studies have also been conducted by Bavrina *et al.*, 2002 in albino plants where a high ratio of Red light in the spectral distribution or Red light irradiance inhibits flowering response in SDPs. Blue in addition to Red LEDs enhanced induction of flowering in cyclamen, the number flower buds and open flowers being most astounding in the plants become under blue in addition to Red LEDs, studied by Heo *et al.* (2003). Higuchi *et al.* (2012) found that the Blue light play an important role in the promotion of flowering under long day conditions. Biondo and Noland (2006) reported that flowering is the consequence of physiological and biochemical procedures, activity of qualities with the impact of photoperiod. Flowering plants have photoreceptor protein for detecting occasional changes in photoperiod, which give the flag for blooming. Flowering plants have a photoreceptor protein to detect regular changes in day length, which go about as signs to blossom. Takemiya *et al.,* 2005 found that plant use light as a source of energy source and as well as environmental signal to reaction to its intensity and direction of flowering.

The role of phoreceptors is very important to wide range of specific physiological responses. Supplemental Blue lighting has important functions in the flowering process. The application of supplemental lighting also allows greenhouse crops to promote biomass accumulation by increasing photosynthetic carbon assimilation as reported by Hao and Papadopoulos (1999). Our findings are in line with experiments conducted by Menard *et al*. (2006), wherein supplemental Blue light could increase plant dry weight in cucumber and tomato. An admixture of Blue + Red light sources may combine the advantages of monochromic Red and monochromic Blue light, and such a mixture may overcome the individual disadvantages of these lights. Therefore, the mixture of Blue + Red light promoted plantlet growth, but the best proportion of B plus R light may be specific to the plant species was revealed by Li *et al.* (2010). In the present experiment we could find that illumination with Red + Blue light is can be a novel idea or system for chrysanthemum cut flower production and crop regulation in overcoming the pronounce effect of natural and interrupted short (SD) and long day (LD) conditions.

Chapter 6

SUMMERY AND CONCLUSION

Chrysanthemum is a major crop in floriculture business; it is cultivated as cut flower, loose flower as well as a pot plant. It can be grown in open as well as controlled conditions. Open field grown crop normally flowers only when natural short days occur. Under protected conditions, flower can be harvested round the year by manipulation the photoperiod. The quality of cut flower depend upon stem length, fresh leaves and attractive flower characters and these characters can be superior when grown under the protected condition the under open conditions. *Chrysanthemum* is also one of the important flowering indoors and pot plants are supplied to demand areas after the bud induction. An early bud induction and compact plant can be produced by manipulating light of specific wavebands.

In the present investigation entitled "Studies on photoperiodic response in *Chrysanthemum morifolium* Ramat.", to explore the possibility of providing long days exposure through LEDs as PAR and to know that which coloured LEDs would give desired results for the cut flower production. Light was provided through LEDs as a long day (15h) to evaluate the effect of LEDs on vegetative growth, cut flower stem length, bud induction and flowering parameters. The effect of LEDs and HPS light in plants was compared and analysed that which specific coloured LEDs resulted in best result in *Chrysanthemum morifolium* Ramat cvs. Zembla and Thai Chen Queen. These two cultivars are popular, produce single/standard flower, good as cut flower under open fields as well as controlled conditions. The results obtained due to an exposure to different coloured LEDs are being summarised as following.

- An increase in plant height was recorded in plants exposed to Blue LEDs and an admixture of Red + Blue LEDs at each 15 days interval as compare with other treatments; maximum plant height at 45 days after keeping plants in growth chamber was recorded under Blue LEDs (66.50 and 44.57 cm in Zembla and Thai Chen Queen, respectively) followed by under mixed Red + Blue LEDs. While the minimum plant height was recorded under Red LEDs i.e. 54.17 and 33.17 cm in Zembla and Thai Chen Queen, respectively.

- Maximum stem diameter was recorded under plants grown under Red LEDs at each 15 days interval; at 45 days stem diameter under Red LEDs recorded 5.60 and 5.53 mm in Zembla and Thai Chen Queen cultivars, respectively followed by mixed Red + Blue LEDs while under Blue LEDs it was found minimum in both cultivars 4.63 and 4.77 mm, respectively.
- A significant difference in internodal length was recorded at different growth period; at 45 days after keeping plants under growth chamber, maximum internode length was recorded recorded 2.29 and 1.92 cm in Zembla and Thai Chen Queen, respectively under the Blue LEDs followed by an admixture of Red + Blue while minimum internodal length was observed under Red LEDs where it recorded 1.94 cm in Zembla and 1.64 cm in Thai Chen Queen.
- Numbers of leaves per plant were not affected by the different light treatments and found non-significant at 15 and 30 days after keeping under growth chamber and found significant at 45 days interval. Maximum numbers of leaves were recorded under Blue LEDs (32.73 and 25.40 in Zembla and Thai Chen Queen, respectively) while minimum numbers of leaves were recorded under Red LEDs (30.47 and 23.63) in both the cultivars.
- Maximum leaf area was recorded under plants exposed with an admixture of Red + Blue LEDs while minimum leaf area was recorded under control among both the cultivars. At 45 days stage in Zembla, a leaf area of 291.40 cm^2 recorded however it was noted 192.33 cm^2 in Thai Chen Queen cultivar; which are relatively 14% while 12% more than that of control (minimum). Leaf area of plants grown under Blue LEDs and Red LEDs is less than an admixture of Red + Blue LEDs but more than that of White LEDs.
- At 15, 30 and 45 days after the plants were kept under different LEDs, maximum leaf area index was recorded under an admixture of Red + Blue LEDs followed by under Blue LEDs and minimum under control. At 45 days, under an admixture of Red + Blue LEDs leaf area index was recorded 2.91 and 1.92 in Zembla and Thai Chen Queen, respectively; while it was recorded 2.56 and 1.72 under control.
- A significant effect of different light treatment on leaf fresh weight was recorded at different days interval. At 45 days, maximum leaf fresh weight was recorded in plants exposed to an admixture of Red + Blue LEDs (15.30g and 11.67g in Zembla and

Thai Chen Queen, respectively) while minimum fresh weight was recorded in plants exposed to HPS light (12.62 and 9.37g respectively in both cultivars).

- A similar trend was observed for dry weight accumulation under different LEDs treatments at which maximum dry weight was recorded under an admixture of Red + Blue LEDs at 15, 30 and 45 days and minimum and control. Under an admixture of Red + Blue LEDs 1.97 and 1.70g leaf dry weight was recorded at 45 days after keeping plants in growth chamber in Zembla and Thai Chen Queen, respectively while under control it recorded 1.46 and 1.39 g, respectively.
- A significant effect of different light treatment on the stem fresh weight was recorded at 15, 30 and 45 days. At 45th days, maximum stem fresh weight was recorded under an admixture of Red + Blue LEDs (10.60g in Zembla and 7.10g in Thai Chen Queen) while minimum stem fresh weight (7.36 and 5.25g in Zembla and Thai Chen Queen, respectively) was observed under control.
- Stem dry weight was estimated maximum under mixed Red + Blue LEDs followed by under Blue LEDs and it found minimum under control. At 45 days, stem dry weight of 3.16 and 2.35g was recorded in Zembla grown under an admixture of Red + Blue and control, respectively while in Thai Chen Queen where 1.82g and 1.32g stem dry weight was recorded under Red + Blue and Blue LEDs, respectively.
- Crop growth rate was found significantly higher under mixed Red + Blue LEDs while it was lowest under control in both the cultivars. Maximum crop growth rate was measured between 30 and 45 days; where in Zembla and Thai Chen Queen 10.24 and 6.60 g m^{-2} day^{-1} crop growth rate was measured under mixed Red + Blue LEDs, these CGR were respectively 29% and 26% higher than that of control of same duration.
- Maximum relative growth was observed under an admixture of Red + Blue LEDs while lowest under the control. It show significant only in 0 to 15 days interval exposing to LEDs where it was 0.028 and 0.023 g g^{-1} day^{-1} under an admixture of Red + Blue LEDs and control, respectively while in Thai Chen Queen, between 0 to at 15 days RGR recorded 0.028 and 0.019 g g^{-1} day^{-1} under an admixture of Red + Blue LEDs and control, respectively.
- Net photosynthetic rate was significantly higher in plants grown under an admixture of Red + Blue LEDs as compare with control. At 45 days it recorded 12.28 µmol m^{-2} s^{-1} in Zembla and 13.04 µmol m^{-2} s^{-1} in Thai Chen Queen under an admixture of Red + Blue LEDs while under control it recorded 7.74 and 8.38 µmol m^{-2} s^{-1} in both

cultivars. At 45 days an increase of 58.6 and 55.6% in net photosynthetic rate was recorded in Zembla and Thai Chen Queen, respectively under an admixture of Red + Blue LEDs as compare with control.

- Stomatal conductance under different light treatments was found non-significant. At each 15 days interval, the stomatal conductance was recorded maximum; in the plants which grown under an admixture of Red + Blue LEDs while under control it was found minimum.
- Net assimilation rate showed a significant difference among plants grown under different treatments of light, it found maximum at 15 days followed by 30 days. In Zembla, cultivar, NAR recorded 6.39, 5.12 and 4.13 g cm^{-2} day^{-1} at 15, 30 and 45 days respectively under an admixture of Red + Blue LEDs while under control 5.08, 4.07 and 3.05 g cm^{-2} day^{-1} respectively at 15, 30 and 45 days. NAR of Thai Chen Queen cultivar recorded 6.03, 4.22 and 3.93 g cm^{-2} day^{-1} under an admixture of Red + Blue LEDs which were respectively 22.06, 30.2 and 40.8% higher than control at 15, 30 and 45 days.
- In Zembla, flower bud appeared at the earliest (42.53 days) under the Blue LEDs followed by mixed Red + Blue LEDs (44.07 days) while most delayed (48.17 days) under the control. In Thai Chen Queen, under the Blue LEDs flower bud initiated earliest at 45.6 days than under an admixture of Red + Blue LEDs (47.33 days) while most delayed under control (52.23 days).
- In both the cultivars i.e. Zembla and Thai Chen Queen took 52.10 and 55.10 days (earliest) respectively under Blue LEDs while 1 to 2 days delayed under an admixture of Red + Blue LEDs to flower opening. Flower opening was found 58.80 and 63.13 days (most delay) under control in both cultivars, respectively.
- Under the mixture of Red and Blue coloured LEDs maximum bud diameter of 7.40 mm was attained in Zembla cultivar while in Thai Chen Queen it recorded 8.30 mm. In both the cultivars minimum bud diameter observed under control. A bud diameter of 6.55 and 7.37 mm was recorded under control in Zembla and Thai Chen Queen, respectively.
- Maximum flower diameter was recorded under mixed Red + Blue LEDs (11.67 and 12.63 cm recorded in Zembla and Thai Chen Queen, respectively) while minimum flower diameter was recorded under control (10.07 and 11.33 cm, respectively).

- In Zembla, maximum cut flower stem length (68.13 cm) was recorded under Blue coloured LEDs followed by an admixture of Red + Blue LEDs (64.50 cm) while minimum stem length recorded under Red LEDs (55.10 cm). Same pattern was observed in Thai Chen Queen where 46.50, 43.50 and 35.07 cm cut stem length recorded under blue, an admixture of Red + Blue and Red LEDs, respectively.
- Highest flower fresh weight recorded under an admixture of Red + Blue LEDs; in Zembla it found 17.67 g while in Thai Chen Queen 18.77 g recorded. Under an admixture of Red + Blue LEDs approx. 25% more flower fresh weight was recorded as compare to control.
- Maximum flower dry weight was recorded under an admixture of Red + Blue LEDs (1.89 and 1.78g in both varieties, respectively) while minimum flower dry weight was observed under control (1.61g and 1.50g in both cultivars, respectively). 17.4 and 18.7% flower dry weight was observed under an admixture of Red + Blue LEDs as compare with control in Zembla and Thai Chen Queen, respectively.

Conclusion

Chrysanthemum cultivation is one of the intensive crop production systems under protected condition. *Chrysanthemum* is a short-day plant and can only be cultivated year-round in greenhouses by manipulating the photoperiod. Production of high quality cut flowers is a challenge for farmers as it flowers only under short days in natural condition. The external quality of cut chrysanthemum is usually evaluated in terms of stem length and leaf and flower characteristics. Under North-Indian conditions, it flowers as soon as short day commence without achieving sufficient stem length. Therefore, light may be provided as long days through smart LEDs to produce the sufficient stem length and quality flower characteristics. Red and Blue LEDs are prominent spectra in which chrysanthemum absorption is acclimatised to the maximum using 80% Red+ 20% Blue illuminated at 110-120 µmol m^{-2} $sec^{-1}$and its recorded that an admixture of Red + Blue LEDs produced best results in relation to plant growth and flowering characteristics. However, HPS lamps are most commonly used light source in greenhouse as normal white light with natural irradiance maintained at 110 µmol m^{-2} sec^{-1} as control. The salient achievements of this research are given below:

1. An admixture of 80% Red + 20% Blue LEDs gave the best result in relation to the plant growth and flowering characteristics.

2. Increase in the plant height was significant and recorded maximum under Blue LEDs followed by an admixture of Red + Blue LEDs while most dwarf plants were produced by Red LEDs.
3. Plants height increase was largely achieved due to extension internodes but not by the number of internodes.
4. Crop growth rate was highest under mixed Red + Blue LEDs while lowest under control.
5. The highest photosynthetic activity was found in the plants exposed under 80% Red + 20% Blue LEDs among all light treatments.
6. Normal flower bud induction could take place, even under long days (15 h/day) when provided from PAR through smart LEDs.
7. The fresh and dry matter accumulation was highest under 80% Red + 20% Blue LEDs and minimum under control (HPS lighting).

Future line of work

Chrysanthemum cultivars / varieties are diverse and have a strong genetic inheritance in terms of photo-thermo sensitivity for natural flower induction. Requirement of short days (SD) for flowering is govern by available natural low irradiance. However, it remains vegetative under continuous long days (LD) conditions under North-Indian conditions. Having been evaluated for their response to flower induction, there is a possibility to induce normal flowering even under long days under an exposure with PAR through smart LEDs and short day period is shorter in winter and long day period is longer in summers. The work on Indian *Chrysanthemum* stock on photoperiodic response to flowering has not been taken up yet. Therefore, there is need to standardize the requirement of light quality in desired wavelength of spectra of higher photosynthetic intensity to categorise them into different reaction time group for flowering thereby, benefiting the farmers with higher economic returns.

ABSTRACT

Studies on photoperiodic response in *Chrysanthemum morifolium* Ramat.

In an experiment conducted on *Chrysanthemum* cvs. Zembla and Thai Chen Queen under photoperiodic treatments from smart LEDs, photo-synthetically active radiation (PAR) through different coloured LEDs viz., White, Blue, Red and an admixture of 80%Red + 20%Blue @ 15h/day was provided along with a control as high pressure sodium (HPS) lighting for 11 h/day under growth chamber. Light intensity was fixed @ 110-120 μmol m^{-2} sec^{-1} in all the treatments using a LED grow panel having 840 LEDs of monochromatic separated into individual colours i.e., White, Blue and Red and an admixture of 80%Red + 20%Blue LEDs. In case of each panel composed of mixed Red and Blue LEDs, every stripped panel was made by fixing 672 Red LEDs and 168 Blue LEDs placed distantly at regular design interval. To achieve a light intensity of @ 110-120 μmol m^{-2} sec^{-1} these strips were backed with a power supply @ 14.4 W/M, voltage input DC 12 V and rating IP22 controlled by an adaptor AC 110~ 220V, 12V 5Amp and these were glued together in an area of 1.0 m x 1.0 m panel so that the distribution of PAR under the growth chamber become uniform. After sufficient hardening, uniform self- rooted cuttings were transplanted in 10 cm pots kept under growth chamber; and temperature and relative humidity regulated at 24±2°C and 60-65% through air conditioners and humidifiers, respectively. Plant grown under different coloured LEDs were exposed for 15 h as long day treatment while under control plants were exposed to HPS light for 11 h.

Among different growth parameters i.e. plant height, stem diameter, internodal length, number of leaves, leaf area, leaf area index, fresh and dry weight of leaf, fresh and dry weight of stem, crop growth rate, relative growth rate, net photosynthetic rate, stomatal conductance varied significantly during different stages of growth and found superior under LEDs than HPS lighting. Increase in plant height (66.50 and 44.57 cm), internodal length (2.29 and 1.92 cm), number of leaves (32.73 and 25.40) were observed maximum in Zembla and Thai Chen Queen under Blue LEDs; these parameters were recorded, minimum internodal length (1.94 and 1.64 cm), number of leaves (30.93 and 23.87) under control while minimum plant height (54.17 and 33.17 cm) noted under Red LEDs, in Zembla and Thai Chen Queen at 45 days. Maximum

stem diameter was recorded under Red LEDs (5.60 and 5.53 mm) while under Blue LEDs it was recorded minimum (4.63 and 4.77 mm) in both cultivars. Maximum leaf area (291.40 and 192.33 $cm^{2)}$), leaf area index (2.91 and 1.92), leaf fresh weight (15.30g and 11.67g), leaf dry weight (1.97 and 1.70g), stem fresh weight (10.60 and 7.10g), stem dry weigh (3.16 and 1.82g), crop growth rate (10.24 and 6.60 g m^{-2} day^{-1}), net photosynthetic rate (12.28 and 13.04 µmol m^{-2} s^{-1}) at 45 days were recorded under an admixture of Red + Blue LEDs in Zembla and Thai Chen Queen, respectively. However, these values recorded were minimum under control. Maximum relative growth rate (0.028 and 0.028 g g^{-1} day^{-1}) were recorded under mixed Red + Blue LEDs and minimum under control (0.023 and 0.019 g g^{-1} day^{-1}) at 15 days in both cultivars while stomatal conductance was found non-significant. Early flower bud induction (6 and 7 days) and flowering (6 and 8 days) was recorded under Blue LEDs in both cultivars than control. A bud diameter (7.40 and 8.30 mm in plants grown under mixed Red + Blue LEDs) and (6.55 and 7.37 mm in control); flower diameter (11.67 and 12.63 cm in admixture of Red + Blue LEDs) and (10.07 and 11.33 in control) was recorded. Maximum cut flower stem length was recorded under Blue LEDs (68.13 and 46.50 cm) while minimum under Red LEDs (55.10 and 35.07 cm). Flower fresh weight (25% more in both cultivars) and dry weight (17.4 and 18.7% increase in both cultivars) was also recorded highest under mixed Red + Blue LEDs and minimum under control. The consistent induction of normal bud and flowering might have resulted in long day (LD) exposure through smart LEDs due to the effect that without disturbing the required minimum dark period for flower induction plants could produce longer stem length and quality flowers.

सार

क्राईसेंथमम मोरीफोलियम रमात. में दीप्तिकालिक अनुक्रिया पर अध्ययन

वृद्धि कक्ष के अंतर्गत क्राईसेंथमम की कृषि-जोपजातियों जेम्बला एवं थाई चेन क्वीन पर प्रकाश संश्लेषण संबंधी सक्रिय विकिरणीय माध्यम के स्मार्ट प्रकाश-उत्सर्जक डायोड (एल ई डी) के विभिन्न वर्णों सफेद, नीला, लाल, मिश्रित 80%लाल + 20%नीला 15 घंटे प्रति दिन एवं उच्च दबाव सोडियम द्वारा सामान्य प्रकाश के 11 घंटे प्रति दिन की दर के प्रभाव में एक प्रयोग संचालित किया गया। प्रयोग में अलग-अलग एल ई डी पैनल बनाकर सभी उपचारों में प्रकाश की तीव्रता 110-120 माइक्रो मोल प्रति वर्ग मीटर प्रति सेकंड नियत की गई, प्रत्येक पैनल 840 एकवर्णी रंग की एल ई डी यानी सफेद, नीला और लाल व मिश्रित 80%लाल + 20%नीला एल ई डी का बनाया गया। मिश्रित लाल और नीला एल ई डी से बने पैनल में नियमित रूप से डिजाइन अंतराल पर लाल (672) एवं नीला (168) एल ई डी से एक पट्टी बनाई गई। 110-120 माइक्रो मोल प्रति वर्ग मीटर प्रति सेकंड की एकसमान प्रकाश तीव्रता प्राप्त करने के लिए इन पट्टियों को बिजली की आपूर्ति हेतु @14.4 डब्ल्यू / एम, वोल्टेज इनपुट डी सी 12 वोल्ट, एडाप्टर एसी 110~220 वोल्ट, 12 वोल्ट 5 एम्पियर, एवं रेटिंग आई पी 22 द्वारा संयोजित कर, 1.0 मी × 1.0 मी पैनल में एक नियमित अंतराल में जोड़ा गया। पौधों के पर्याप्त वृद्धिमय होने के पश्चात, 10 सेमी व्यास के गमलों को वृद्धि कक्ष में रखा गया; और तापमान एवं सापेक्ष आर्द्रता को वातानुकूलक और हुमिडिफिएर्स के माध्यम से क्रमशः 24±2 डिग्री सेल्सियस और 60-65% पर नियंत्रित किया गया। विभिन्न एल ई डी के अंतर्गत उगाये पौधों को 15 घंटे के लंबे दिनों के उपचार के लिए प्रकाशित किया, जबकि एच पी एस बल्बों से सामान्य प्रकाश के अंतर्गत उगाये गए पौधों को 11 घंटे के प्रकाश से प्रकाशित कराया गया।

विभिन्न वृद्धि प्रांचलों में पादप की ऊंचाई, तने का व्यास, अंतर-गांठ लंबाई, पत्तियों की संख्या, पत्ती क्षेत्र, पत्ती क्षेत्र सूचकांक, पत्ती का ताजा एवं शुष्क भार, तने का ताजा एवं शुष्क भार, फसल वृद्धि दर, सापेक्ष वृद्धि दर, शुद्ध प्रकाश संश्लेषण दर, एवं विकास के विभिन्न वृद्धि अवस्थाओं के दौरान महत्वपूर्ण भिन्नतायें देखी गई और एचपीएस प्रकाश की अपेक्षा एल ई डी के अंतर्गत बेहतर परिणाम पाए गए। पादप ऊँचाई (66.50 और 44.57 सेमी), अंतर-गांठ लंबाई (2.29 और 1.92 सेमी), पत्तियों की संख्या (32.73 और 25.40) में वृद्धि नीला एल ई डी के अंतर्गत जेम्बला और थाई चेन क्वीन में अधिकतम देखी गई; इन प्रांचलों में पादप ऊंचाई (54.17 और

33.17 सेमी) लाल एल ई डी के अंतर्गत, जबकि अंतर-गांठ लम्बाई (1.94 और 1.64 सेमी), पत्तियों की संख्या (30.93 और 23.87) जेम्बला और थाई चेन क्वीन पर 45 दिनों के दौरान के न्यूनतम परिणाम दर्ज किये गए। दोनों कृषि-जोपजातियों में अधिकतम तना व्यास (5.60 और 5.53 मिमी), लाल एल ई डी के अंतर्गत, जबकि नीला एल ई डी के तहत यह न्यूनतम (4.63 और 4.77 मिमी) दर्ज किया गया। अधिकतम पत्ती क्षेत्र (291.40 और 192.33 वर्ग सेमी), पत्ती क्षेत्र सूचकांक (2.91 और 1.92), पत्ती ताजा भार (15.30 और 11.67 ग्रा.), पत्ती शुष्क भार (1.97 और 1.70 ग्रा.), तना ताजा भार (10.6 और 7.10 ग्रा.) , तना शुष्क भार (3.16 और 1.82 ग्रा.), फसल वृद्धि दर (10.24 और 6.60 ग्राम प्रति वर्ग मीटर मीटर प्रति दिन), शुद्ध प्रकाशसंश्लेषण दर (12.28 और 13.04 माइक्रो मोल प्रति वर्ग मीटर प्रति सेकंड), 45 दिनों में मिश्रित लाल और नीला एल ई डी के अंतर्गत क्रमशः जेम्बला और थाई चेन क्वीन में दर्ज किये गए। जबकि इन प्रांचलों को कन्ट्रोल के तहत न्यूनतम दर्ज किया गया। अधिकतम सापेक्ष वृद्धि दर 15 दिन में, (0.028 और 0.028 ग्रा. प्रति ग्रा. प्रति दिन) मिश्रित लाल और नीला एल ई डी के अंतर्गत और कन्ट्रोल में न्यूनतम (0.023 और 0.019 ग्रा. प्रति ग्रा. प्रति दिन) क्रमशः जेम्बला और थाई चेन क्वीन में दर्ज की गई, जबकि रंध्र संबंधी प्रवाहकत्त्व गैर महत्वपूर्ण पाया गया। कलिका आगमन (6 और 7 दिन अग्रिम) और पुष्पन (6 और 8 दिन अग्रिम) दोनों कृषि-जोपजातियों में नीला एल ई डी के अंतर्गत कन्ट्रोल से अग्रिम दर्ज की गई। कलिका व्यास (7.40 और 8.30 मिमी मिश्रित लाल और नीला एल ई डी के अंतर्गत) और (6.55 और 7.37 मिमी कन्ट्रोल में); पुष्प व्यास (11.67 और 12.63 सेमी मिश्रित लाल और नीला एल ई डी के अंतर्गत) और (10.07 और 11.33 सेमी कन्ट्रोल में) दर्ज किये गए। अधिकतम कर्तित पुष्प लंबाई (68.13 और 46.50 सेमी) नीला एल ई डी के अंतर्गत दर्ज दर्ज की गई, जबकि लाल एल ई डी के प्रभाव में न्यूनतम (55.10 और 35.07 सेमी) दर्ज की गई। पुष्प ताजा भार (दोनों कृषि-जोपजातियों में कन्ट्रोल से 25% अधिक) और पुष्प शुष्क भार (दोनों कृषि-जोपजातियों में कन्ट्रोल से 17.4 और 18.7% वृद्धि) भी मिश्रित लाल और नीला एल ई डी के अंतर्गत सबसे ज्यादा और कन्ट्रोल में न्यूनतम दर्ज किये गये। सामान्य कलिका और पुष्प आगमन, प्रकाश उत्सर्जक डायोड स्वरुप स्मार्ट एल ई डी के माध्यम से संगत लंबे दिनों में भी संभव हो सकता है जिससे कि आवश्यक अंधकार अवधि में अंतर हुए बिना लम्बे कर्तित पुष्प उच्च गुणवत्ता के उत्पादित किये जा सकते हैं।

BIBLIOGRAPHY

Adams, S. R. Pearson, S. and Hadley, P. 1998. The effect of temperature on inflorescence initiation and subsequent development in chrysanthemum cv. Snowdon (*Chrysanthemum× morifolium* Ramat.). *Scientia Horticulturae*, **77(1):** 59-72.

Ahmad, M. and Cashmore, A. R. 1993. HY4 gene of *A. thaliana* encodes a protein with characteristics of a blue-light photoreceptor. *Nature*, **366:** 162–166.

Anonymous. 2017. 2nd Advance Estimate of Area and Production of Horticulture Crops (2016-2017), *National Horticulture Board,* 5-6.

Armitage, A. M. and Tsujita, M. J. 1979. Supplemental lighting and nitrogen nutrition effects on yield and quality of "Forever Yours" roses. *Canadian Journal of Plant Science*, **59(2):** 343-350.

Bagnall, D. J., King, R. W. and Hangarter, R. P. 1996. Blue-light promotion of flowering is absent in hy4 mutants of Arabidopsis. *Planta*, **200(2):** 278-280.

Ballare, C. L., Sanchez, R. A., Scopel, A. L., Casal, J. J. and Ghersa, C. M. 1987. Early detection of neighbour plants by phytochrome perception of spectral changes in reflected sunlight. *Plant, Cell & Environment*, **10(7):** 551-557.

Barnes, C. and Bugbee, B. 1991. Morphological responses of wheat to changes in phytochrome photoequilibnum. *Plant Physiology,* **97(1):** 359-365.

Barta, D. J., Tibbitts, T. W., Bula, R. J. and Morrow, R. C.1992. Evaluation of light emitting diode characteristics for a space-based plant irradiation source. *Advances in Space Research,* **12(5):** 141-149.

Bavrina, T. V., Lozhnikova, V. N., Cculaficc, L. and Zhivanovich, B. 2002. Flowering of cultivated green and SAN 9789-treated *Chenopodium rubrum* plants exposed to white, blue, and red light. *Russian journal of Plant Physiology*, **49(4):** 460-464.

Biondo, R. J. and Noland, D. A. 2006. Floriculture from greenhouse production to floral design. *International Book Distributing Co.,* Lucknow, 144-166.

Brazaityte, A., Ulinskaite, R., Duchovskis, P., Samuoliene, G., Siksnianiene, J.B., Jankauskiene , J., Sabajeviene, G., Baranauskis, K., Staniene, G., Tamulaitis, G., Bliznikas, Z. and Zukauskas, A. 2006. Optimisation of lighting spectrum for photosynthetic system and productivity of lettuce by using light-emitting diodes. *Acta Horticulturae,* **711:** 183-188.

Brown, C. S., Schuerger, A. C. and Sager, J. C. 1995. Growth and photomorphogenesis of pepper plants under red light-emitting diodes with supplemental blue or far-red lighting. *Journal of the American Society for Horticultural Science*, **120(5):** 808-813.

Calthy, H. M. 1955. Chrysanthemum temperature study: Thermal modification of photoperiods precious to and after flower bud initiation. *Proceedings of the American Society for Horticulture Science*, **66:** 492-502.

Calthy, H. M. 1974. Participation of phytochrome in regulating inter-node elongation of *Chrysanthemum morifolium* (Ramat). *Journal of the American Society for Horticultural Science,* **99:** 17-23.

Carvalho, S. M. P. and Heuvelink, E. 2003. Effect of assimilate availability on flower characteristics and plant height of cut chrysanthemum: an integrated study. *The Journal of Horticultural Science and Biotechnology*, **78(5):** 711-720.

Carvalho, S.M.P., Tarabay, H. and Heuvelink, E. 2005. Temperature affects chrysanthemum flower characteristics differently during three phases of the cultivation period. *Journal of Horticultural Science and Biotechnology.* **80:** 209-216.

Casal, J. J. and Smith, H. 1988. The loci of perception for phytochrome control of internode growth in light-grown mustard: Promotion by low phytochrome photoequilibria in the internode is enhanced by blue light perceived by the leaves. *Planta,* **176(2):** 277-282.

Chee, R. 1986. In vitro culture of Vitis: the effects of light spectrum, manganese sulfate and potassium iodide on morphogenesis. *Plant Cell, Tissue and Organ Culture*, **7(2):** 121-134.

Chen, M., Chory, J. and Fankhauser, C. 2004. Light signal transduction in higher plants. *Annual Review of Genetics,* **38:** 87–117.

Clifford, S. C., Runkle, E. S., Langton, F. A., Mead, A., Foster, S. A., Pearson, S. and Heins, R. D. 2004. Height control of poinsettia using photoselective filters. *HortScience*, **39(2):** 383-387.

Cockshull, K. E. 1976. Flower and leaf initiation by *Chrysanthemum morifolium* Ramat in long days. *Journal of Horticultural Science,* **51(4):** 441-450.

Cosgrove, D. J. 1981. Rapid suppression of growth by blue light. *Plant Physiology,* **67(3):** 584–590.

Curry, C. J. and Ervin, J. E. 2010. Variation among *Kalanchoe species* in their flowering responses to photoperiod and short-day cycle number. *Journal of Horticultural Science and Biotechnology,* **85(4):** 350-354.

Deutch, B. and Rasmussen, O. 1974. Growth chamber illumination and photomorphogenetic efficacy I. Physiological action of infrared radiation beyond 750 mm. *Physiologia Plantarum,* **30(1):** 64-71.

Dole, J. M. and Wilkins, H. F. 2005. Floriculture: Principles and Species, 2nd edition. Pearson Prentice Hall, Upper Saddle River, New Jersey.

Erwin, J. E. and Warner, R. M. 2000. Determination of photoperiodic response group and effect of supplemental irradiance on flowering of several bedding plant species. In *IV International ISHS Symposium on Artificial Lighting,* **580:** 95-99.

Faust, J. E., Holcombe, V., Rajapakse, N. C. and Layne, D. R. 2005. The effect of daily light integral on bedding plant growth and flowering. *HortScience*, **40(3):** 645-649.

Fisher, R. A. 1921. Some remarks on the methods formulated in a recent article on "The quantitative analysis of plant growth". *Annals of Applied Biology*, **7(4):** 367-372.

Flint, L. H. 1934. Light in relation to germination and dormancy in lettuce seeds. *Science,* **80:** 38–40.

Folta, K. M. and Childers, K. S. 2008. Light as a growth regulator: controlling plant biology with narrow-bandwidth solid-state lighting systems. *HortScience*, **43(7):** 1957-1964.

Folta, K. M. and Maruhnich, S. A. 2007. Green light: a signal to slow down or stop. *Journal of Experimental Botany*, **58(12):** 3099-3111.

Fosket, D. E. 1994. Plant Growth and Development, a Molecular Approach. Academic press, San Diego, California.

Franklin, K. A. 2008. Shade avoidance. *New Phytologist*, **179(4):** 930-944.

Furuta, T. 2004. Photoperiod and flowering of *Chrysanthemums*. *Scientia Horticulturae,* **63:** 457-461.

Garner, W. W. and Allard, H. A. 1920. Effect of the relative length of day and night and other factors of the environment on growth and reproduction in plants. *Journal of Agricultural Research,* **18:** 553-603.

Gilbert, I. R., Seavers, G. P., Jarvis, P. G. and Smith, H. 1995. Photomorphogenesis and canopy dynamics phytochrome-mediated proximity perception accounts for the growth dynamics of canopies of *Populus trichocarpa X deltoides* 'Beaupré'. *Plant Cell & En*vironment, **18(5):** 475–497.

Gislerod, H. R. and Nelson, P. V. 1997. Effect of relative air humidity and irradiance on growth of *Dendranthema x grandiflorum* (Ramat.) Kitamura. *Gartenbauwissenschaft,* **62(5):** 214-217.

Goins, G. D., Yorio, N. C., Sanwo, M. M. and Brown, C. S. 1997. Photomorphogenesis, photosynthesis, and seed yield of wheat plants grown under red light-emitting diodes (LEDs) with and without supplemental blue lighting. *Journal of Experimental Botany*, **48(7):** 1407-1413.

Graham, H. A. H. and Decoteau, D. R. 1997. Young watermelon plant growth responses to end-of-day red and far-red light are affected by direction of exposure and plant part exposed. *Scientia Horticultura,* **69(1):** 41-49.

Gregory, F. G. 1926. The effect of climatic conditions on the growth of barley. *Annals of Botany*, **40(157):** 1-26.

Hangarter, R. P. and Stasinopoulos, T. C. 1991. Repression of plant tissue culture growth by light is caused by photochemical change in the culture medium. *Plant Science,* **79(2):** 253–257.

Hao, X. and Papadopoulos, A. P. 1999. Effects of supplemental lighting and cover materials on growth, photosynthesis, biomass partitioning, early yield and quality of greenhouse cucumber. *Scientia Horticulturae,* **80(1):** 1-18.

Heo, J. W., Lee, C. W., Murthy, H. N. and Paek, K. Y. 2003. Influence of light quality and photoperiod on flowering of and lt;I and gt; *Cyclamen persicum* Mill. cv. 'Dixie White'. *Plant Growth Regulation,* **40(1):** 7-10.

Heo, J., Lee, C., Chakrabarty, D. and Paek, K. 2002. Growth responses of marigold and salvia bedding plants as affected by monochromic or mixture radiation provided by a light-emitting diode (LED). *Plant Growth Regulation*, **38(3):** 225-230.

Higuchi, Y., Sage-Ono, K., Sasaki, R., Ohtsuki, N., Hoshino, A., Iida, S. and Ono, M. 2011. Constitutive expression of the GIGANTEA ortholog affects circadian rhythms and suppresses one-shot induction of flowering in Pharbitis nil, a typical short-day plant. *Plant and Cell Physiology*, **52(4):** 638-650.

Hirai, T., Amaki, W. And Watanabe, H. 2006. Action of blue or red monochromatic light on stem internodal growth depends on plant species. In *V International Symposium on Artificial Lighting in Horticulture,* **711:** 345-350.

Hisamatsu, T., Sumimoto, K. and Shimizu, H. 2008. End-of day far-red treatment enhances responsiveness to gibberellins and promotes stem extension in chrysanthemum. *The Journal of Horticultural Science and Biotechnology,* **83(6):** 695-700.

Hoeven, V. D. 1987. Chrysanthemum production in the Netherlands. *Acta Horticulturae,* **197:** 11-19.

Hogewoning, S. W., Trouwborst, G., Maljaars, H., Poorter, H., van Ieperen, W. and Harbinson, J. 2010. Blue light dose–responses of leaf photosynthesis, morphology, and chemical composition of Cucumis sativus grown under different combinations of red and blue light. *Journal of Experimental Botany*, **61(11):** 3107-3117.

Horridge, J. S., Pegler, J. E. and Atke, P. T. 1984. A study of the leaf and inflorescence initiation and development in *Chrysanthemum morofolium* Ramat. cv. Showdon by scanning electron microscopy. In: Annual report glasshouse crops research institute 1983. *Littlehampton:GCRI,* 171-183.

Hughes, A. P. and Cockshull, K. E. 1971. The Effects of Light Intensity and Carbon Dioxide Concentration on the Growth of *Chrysanthemum morifolium* cv. Bright Golden Anne. *Annals of Botany,* **35 (4):** 899-914.

Islam, M. A., Kuwar, G., Clarke, J. L., Blystad, D. R., Gislerod, H. R., Olsen, J. E. and Torre, S. 2012. Artificial light from light emitting diodes (LEDs) with a high portion of blue light results in shorter poinsettias compared to high pressure sodium (HPS) lamps. *Scientia Horticulturae,* **147:** 136–143.

Islam, N., Patil, G. G. and Gislerod, H. R. 2005. Effect of photoperiod and light integral on flowering and growth of *Eustoma grandiflorum* (Raf.) Shinn. *Scientia Horticulturae*, **103(4):** 441-451.

Jeong, S. W., Hogewoning, S. W. and Ieperen, W. V. 2014. Responses of supplemental blue light on flowering and stem extension growth of cut chrysanthemum. *Scientia Horticulturae,* **165:** 69–74.

Jeong, S. W., Park, S., Jin, J. S., Seo, O., Kim, G. S., Kim, Y. H., Bae, H., Lee, G., Kim, S. T., Lee, W.S. and Shin, S. C. 2012. Influences of four different light-emitting diode lights on flowering and polyphenol variations in the leaves of chrysanthemum. *Journal of Agricultural and Food Chemistry,* **60(39):** 9793-9800.

Jiang, B. B., Chen, S. M., Miao, H. B., Zhang, S. M., Chen, F. D. and Fang, W. M. 2010. Changes of endogenous hormone levels during short-day inductive floral initiation and inflorescence differentiation of Chrysanthemum morifolium 'Jingyun'. *International Journal of Plant Production*, **4(2):** 149-157.

Karlsson, M. G. and Werner, J. W. 2002. Flowering of Primula malacoides in response to photoperiod and temperature. *Scientia Horticulturae,* **95(4):** 351-356.

Karlsson, M. G., Heins, R. D., Erwin, J. E., Berghage, R. D., Carlson, W. H. and Biernbaum, J. A. 1989. Temperature and photosynthetic photon flux influence chrysanthemum shoot development and flower initiation under short-day conditions. *Journal of the American Society for Horticultural Science,* **114(1):** 158–163.

Kaur, P. and Singh, K. 2016. Regulation of Flower Production in chrysanthemum (*Chrysanthemum morifolium* Ramat.) Through Photoperiodic Treatments. *Agricultural Research Journal,* **53(2):** 224-227.

Kendrick, R. E. and Kronenberg, G. H. M. 1994. Photomorphogenesis in Plants. *2nd ed. K. A. (Publishers, ed.), Kluwer, Dordrecht.*

Khattak, A. M. and Pearson, S. 1996. The effects of light quality and temperature on the growth and development of chrysanthemum cvs. Bright Golden Anne and Snowdon. In *II Workshop on Environmental Regulation of Plant Morphogenesis,* **435:** 113-122.

Khattak, A. M., Pearson, S. and Johnson, C. B. 2004. The effects of far red spectral filters and plant density on the growth and development of chrysanthemums. *Scientia Horticulturae*, **102(3):** 335-341.

Kim, H. H., Goins, G., Wheeler, R. and Sager, J. 2004. Stomatal Conductance of Lettuce Grown Under or Exposed to Different Light Qualities. *Annals of Botany,* **94(5):** 691–697.

Kim, H. H., Heins, R. D. and Carlson, W. H. 2002. Development and flowering of Petunia grown in a far red deficient light environment. *Acta Horticulturae,* **580:** 127–135.

Kim, S. J., Hahn, E. J., Heo, J. W. and Paek, K. Y. 2004. Effects of LEDs on net photosynthetic rate, growth and leaf stomata of chrysanthemum plantlets *in vitro*. *Scientia Horticulturae*, **101(1):** 143-151.

Kleine, T., Lockhart, P. And Batschauer, A. 2003. An Arabidopsis protein closely related to Synechocystis cryptochrome is targeted to organelles. *The Plant Journal,* **35(1):** 93–103.

Kobayashi, Y. and Weigel, D. 2007. Move on up, it's time for change—mobile signals controlling photoperiod-dependent flowering. *Genes and Development,* **21(19):** 2371–2384.

Kubota, S., Yamato, T., Hisamatsu, T., Esaki, S., Oi, R., Roh, M. S. and Koshioka, M. 2000. Effects of red-and far-red-rich spectral treatments and diurnal temperature alternation on the growth and development of Petunia. *Journal of the Japanese Society for Horticultural Science*, **69(4):** 403-409.

Kumar, S. and Singh, M. C. 2017. Effect of photoperiod on growth characteristics in Chrysanthemum morifolium Ramat. cv. Zembla. *Research on Crops*, **18(1):** 110-115.

Kurilcik, A., Canova, R. M., Dapkunienė, S., Zilinskaite, S., Kurilcik. G., Tamulaitis, G., Duchovskis, P. and Zukauskas, A. 2008. *In-vitro* culture of *Chrysanthemum* plantlets using light-emitting diodes. *Central European Journal of Biology*, **3(2):** 161–167.

Li, H., Tang, C. and Xu, Z. 2013. The effects of different light qualities on rapeseed (Brassica napus L.) plantlet growth and morphogenesis *in vitro*. *Scientia Horticulturae,* **150:** 117-124.

Li, H., Xu, Z. and Tang, C. 2010. Effect of light-emitting diodes on growth and morphogenesis of upland cotton (Gossypium hirsutum L.) plantlets in vitro. *Plant Cell, Tissue and Organ Culture*, **103(2):** 155-163.

Lian, M. L., Murthy, H. N. and Paek, K. Y. 2002. Effects of light emitting diodes (LED) on the in vitro induction and growth of bulblets of Lilium oriental hybrid 'Pesaro'. *Scientia Horticulturae,* **94(3):** 365–370.

Lin, Y., Li, J., Li, B., He, T. and Chun, Z. 2011. Effects of light quality on growth and development of protocorm-like bodies of Dendrobium officinale *in vitro. Plant Cell, Tissue and Organ Culture*, **105(3):** 329-335.

Macedo, A. F., Leal-Costa, M. V., Tavares, E. S., Lage, C. L. S. and Esquibel, M. A. 2011. The effect of light quality on leaf production and development of in vitro-cultured plants of Alternanthera brasiliana Kuntze. *Environmental and Experimental Botany,* **70(1):** 43-50.

Mangon, M. H. 1861. Production of the green matter of leaves under the influence of the electric light. *Philosophical Magazine Series* 4, 327-328.

Massa, G. D., Kim, H. H., Wheeler, R. M. and Mitchell, C. A. 2008. Plant productivity in response to LED lighting. *HortScience*, **43(7):** 1951-1956.

Mathews, S. 2006. Phytochrome mediated development in land plants: red light sensing evolves to meet the challenges of changing light environments. *Molecular Ecology,* **15(12):** 3483-3503.

Mattson, N. S. and Erwin, J. E. 2005. The impact of photoperiod and irradiance on flowering of several herbaceous ornamentals. *Scientia Horticulturae,* **104(3):** 275–292.

McCree, K. J. 1971. The action spectrum, absorptance and quantum yield of photosynthesis in crop plants. *Agricultural Meteorology*, **9:** 191-216.

McMahon, M. 1999. Development of chrysanthemum meristems grown under far-red absorbing filters and long or short photoperiods *Journal of the American Society for Horticultural Science,* **124(5):** 483-487.

Menard, C., Dorais, M., Hovi, T. and Gosselin, A. 2006. Developmental and physiological responses of tomato and cucumber to additional blue light. *Acta Horticulturae*, **711:** 291.

Mer, M. S. and Attri, B. L. 2015. Effect of photoperiod on flowering in ornamental annuals. *Journal of Medicinal Plants Studies*, **3(4):** 121-126.

Mockler, T., Yang, H., Yu, X., Parikh, D., Cheng, Y., Dolan, S. and Lin, C. 2003. Regulation of photoperiodic flowering by *Arabidopsis* photoreceptors. *Proceedings of the National Academy of Sciences,* **100(4):** 2140-2145.

Moe, R. 1997. Physiological aspects of supplementary lighting in horticulture. *Acta Horticulturae,* **418:** 17–24.

Morrow, R. C. 2008. LED lighting in horticulture. *HortScience*, **43(7):** 1947–1950.

Mortensen, L. M. and Stromme, E. 1987. Effects of light quality on some greenhouse crops. *Scientia Horticulturae,* **33(1-2):** 27-36.

Nhut, D. T. and Nam, N. B. 2010. Light-emitting diodes (LEDs): an artificial lighting source for biological studies. In *The Third International Conference on the Development of Biomedical Engineering in Vietnam,* 134-139. Springer Berlin Heidelberg.

Nhut, D. T., Takamura, T., Watanabe, H., Okamoto, K. and Tanaka, M. 2003. Responses of strawberry plantlets cul-tured in vitro under superbright red and blue light-emitting diodes (LEDs). *Plant Cell, Tissue and Organ Culture,* **73(1):** 43-52.

Ouzounis, T., Fretté, X., Rosenqvist, E. and Ottosen, C. O. 2014. Spectral effects of supplementary lighting on the secondary metabolites in roses, chrysanthemums, and campanulas. *Journal of Plant Physiology*, **171(16):** 1491-1499.

Oyaert, E., Volckaert, E. and Debergh, P. C. 1999. Growth of chrysanthemum under coloured plastic films with different light qualities and quantities. *Scientia Horticulturae*, **79(3):** 195-205.

Patil, G. G., Oi, R., Gissinger, A. and Moe, R. 2001. Plant morphology is affected by light quality selective plastic films and alternating day and night temperature. *Gartenbauwissenschaft*, **66(2):** 53-60.

Pietsch, G. M., Carlson, W. H., Heins, R. D. and Faust, J. E. 1995. The Effect of Day and Night Temperature and Irradiance on Development of *Catharanthus roseus* (L.) ‘Grape Cooler'. *Journal of the American Society for Horticultural Science*, **120(5):** 877-881.

Post, K. 1948. Day length and flower bud development in chrysanthemum. *Proceedings of the American Society for Horticulture Science*, **55:** 590-592.

Pramuk, L. A. and Runkle, E. S. 2005. Modeling growth and development of Celosia and Impatiens in response to temperature and photosynthetic daily light integral. *Journal of the American Society for Horticultural Science*, **130(6):** 813-818.

Runkle, E. and Fisher, P. 2004. Lighting Up Profits: Understanding Greenhouse Lighting, Photoperiod and flowering. *Meister Media Worldwide, Willoughby, OH,* 25–32.

Runkle, E. S. and Heins, R. D. 2005. Manipulating the light environment to control flowering and morphogenesis of herbaceous plants. In *V International Symposium on Artificial Lighting in Horticulture,* **711:** 51-60.

Runkle, E.S., and Heins, R. D. 2001. Specific functions of red, far red, and blue light in flowering and stem extension of long-day plants. *Journal of the American Society for Horticultural Science,* **126(3):** 275-282.

Saebo, A., Krekling, T. and Appelgren, M. 1995. Light quality affects photosynthesis and leaf anatomy of brich plantlets in vitro. *Plant Cell, Tissue and Organ Culture,* **41(2):** 177–185.

Sager, J. C. and McFarlane, J. C. (1997). Radiation. *Plant Growth Chamber Handbook*, 1-29.

Schuerger, A. C., Brown, C. S. and Stryjewski, E. C. 1997. Anatomical features of Papper plants (*Capsicum annuum L.*) grown under Red Light-emitting Diodes Supplemented with Blue or Far red Light. *Annals of Botany,* **79(3):** 273–282.

Schwabe, W. W. 1951. Factors controlling Flowering in the Chrysanthemum: II. Day-length Effects on the Further Development of Inflorescence Buds and Their experimental Reversal and Modification. *Journal of Experimental Botany,* **2(2):** 223-237.

Shin, K. S., Murthy, H. N., Heo, J. W., Hahn, E. J. and Paek, K. Y. 2008. The effect of light quality on the growth and development of in vitro cultured *Doritaenopsis* plants. *Acta Physiologiae Plantarum*, **30(3):** 339-343.

Singh, M. C., Van Leperen, W., and Heuvelink, E. 2013. Effect of LEDs on flower induction in *Chrysanthemum morifoloium*. *Hort Flora Research Spectrum,* **2(3)**: 185-188.

Smith, H. 1982. Light quality, photoperception and plant strategy. *Annual* Review of *Plant Physiology,* **33(1):** 481-518.

Spaargaren, J. J. 2002. *De teelt van jaarrondchrysanten* [Cultivation of year-round cut chrysanthemum]. *Aalsmeer: Spaargaren.*

Takemiya, A., Inoue, S., Doi, M., Koinoshita, T. and Shimaxaki, K. 2005. Phototropins promote plant growth in response to blue light in low light environment. *Plant Cell,* **17(4):** 1120-1127.

Tanaka, M., Takamura, T., Watanabe, H., Endo, M., Yanagi, T. and Okamoto, K. 1998. In vitro growth of *Cymbidium* plantlets cultured under super bright red and blue light-emitting diodes (LEDs). *The Journal of Horticultural Science and Biotechnology,* **73:** 39-44.

Tennessen, D. J., Singsaas, E. L. and Sharkey, T. D. 1994. Light-emitting diodes as a light source for photosynthesis research. *Photosynthesis Research*, **39(1):** 85-92.

Thomas, B. and Vince-Prue, D. 1997. Photoperiodism in Plants. *2nd ed. Academic Press, New York, USA.*

Tibbitts, T. W., Morgan, D. C. and Warrington, I. J. 1983. Growth of lettuce, spinach, mustard, and wheat plants under four combinations of high-pressure sodium, metal halide, and tungsten halogen lamps at equal PPFD. *Journal of the American Society for Horticultural Science,* **108(4):** 622-630.

Trip, G., Huirne, R. B. M. and Renkema, J.A. 2000. Price-predicting ability of farm managers: empirical findings with flower producers in the Netherlands. Review *of Agricultural Economics,* **22:** 464-476.

Tripathy, B. C. and Brown, C. S. 1995. Root-shoot interaction in the greening of wheat seedlings grown under red light. *Plant Physiology*, **107(2):** 407-411.

Trouwborst, G., Oosterkamp, J., Hogewoning, S. W., Harbinson, J. and Van Ieperen, W. 2010. The responses of light interception, photosynthesis and fruit yield of cucumber to LED-lighting within the canopy. *Physiologia Plantarum*, **138(3):** 289-300.

Van der Hoeven, A. P. 1987. Chrysanthemum production in the Netherlands. *Acta Horticulturae,* **197:** 11-19.

Van der Ploeg, A. and Heuvelink, E. 2006. The influence of temperature on growth and development of chrysanthemum cultivars. *The Journal of Horticultural Science and Biotechnology*, **81(2):** 174-182.

Van Ieperen, W. and Trouwborst, G. 2007. The application of LEDs as assimilation light source in greenhouse horticulture: a simulation study. In *International Symposium on High Technology for Greenhouse System Management: Greensys,* **801:** 1407-1414.

Van Ittersum, M. K., Leffelaar, P. A., Van Keulen, H., Kropff, M. J., Bastiaans, L. & Goudriaan, J. 2003. On approaches and applications of the Wageningen crop models. *European Journal of Agronomy*, **18(3):** 201-234.

Vince, D. 1955. Some Effects of Temperature and Day - Length on Flowering in the Chrysanthemum. *Journal of Horticultural Science,* **30(1):** 34-42.

Vince-Prue, D. 1975. Encyclopedia of Plant Physiology: Photomorphogenesis and Flowering. *McGraw-Hill,* London, **16:** 457-490.

Watson, D. J. 1947. Comparative physiological studies on the growth of field crops: I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years. *Annals of Botany*, **11(41):** 41-76.

Wheeler, R. M., Mackowiak, C. L. and Sager, J. C. 1991. Soybean stem growth under high-pressure sodium with supplemental blue lighting. *Agronomy Journal,* **83(5):** 903-906.

Whiteman, C. W., Heins, R. D., Cameron, A. C. and Carlson, W. H. 1998. Lamp Type and Irradiance Level for Daylength Extensions Influence Flowering of *Campanula carpatica* `Blue Clips', *Coreopsis grandiflora* `Early Sunrise', and *Coreopsis verticillata* `Moonbeam'. *Journal of the American Society for Horticultural Science,* **123(5):** 802-807.

Wieland, C. E. 1998. An examination of night length effects on the difference in floral initiation and floral development of chrysanthemum cultivars. *Masters Thesis, University of Florida, Gainesville, Florida.*

Yeh, H. and Chung, J. P. 2009. High-brightness LEDs-energy efficient lighting sources and their potential in indoor plant cultivation. *Renewable and Sustainable Energy Reviews*, **13(8):** 2175–2180.

Yorio, N. C., Goins, G. D., Kagie, H. R., Wheeler, R. M. and Sager, J. C. 2001. Improving spinach, radish, and lettuce growth under red light-emitting diodes (LEDs) with blue light supplementation. *HortScience*, **36(2):** 380-383.