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Project number:	PC 296
Project leader:	Stage One Dr Steve Adams, University of Warwick, School of Life Sciences, Wellesbourne Campus Stage Two Dr Steve Jackson and Professor Brian Thomas, University of Warwick, School of Life Sciences, Wellesbourne Campus
Report:	Final Report, May 2012
Previous report:	Interim Report, July 2010
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AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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CONTENTS

Abbreviations

Throughout the report the following abbreviations will be used:

CF	Compact Fluorescent
T	Tungsten
LED	Light emitting diode
DE	Day Extension
NB	Night Break
SD	Short Day
LD	Long Day
B	Blue
R	Red
FR	Far-Red
DR/W	Deep Red and White
DR/W/FR	Deep Red, White and Far-Red
SE	Standard Error
LSD	Least significant difference

GROWER SUMMARY

Headline

- Flowering and/or tuber formation in chrysanthemum, poinsettia, begonia and fuchsia was controlled as effectively by compact fluorescent (CF) lighting as it was by tungsten (T) lighting. However, for antirrhinum, Christmas cactus, lisianthus, pansy and petunia the light spectrum from CF lamps did not match that from T lamps well enough to control flowering successfully.
- Deep Red, White and Far-Red (DR/W/FR) LED flowering lamps were able to control flowering and/or tuber formation as effectively as T in chrysanthemum, poinsettia, begonia, antirrhinum, lisianthus, pansy and petunia. However, for Christmas cactus none of the flowering lamps were able to control flowering to the same extent as T lamps.
- Although each species had subtly different optimums, combinations of red (R) and far-red (FR) LED modules were effective at controlling flowering and/or tuber formation for all of the species tested.

Background

Photoperiod lighting can be used to promote flowering in long-day plants (LDP) and to delay or prevent flowering in short-day plants (SDP). Tungsten (T) lamps have traditionally been used for this purpose as they are cheap to purchase and have a suitable light quality. However, Defra have announced that 'inefficient' T lamps will be phased out over the period Jan 2008 to Dec 2011 and higher wattage lamps are already becoming difficult to obtain. Furthermore, there is a desire from some growers to move away from T to minimise stretching which can occur as a consequence of the light spectrum. Consequently, there is a need to assess the suitability of alternative lamps.

The first stage of this project (2009-2010) examined the suitability of replacing inefficient T lamps with compact fluorescent (CF) lamps for daylength control by investigating the flowering responses of a range of horticultural species to CF light quality and quantity. Flowering and/or tuber formation was not controlled as well by CF lighting for over half of the species tested; therefore, CF lamps did not match the light spectrum from T lamps well enough to control flowering effectively for this range of species. As CF lamps lack far-red (FR) light, the solution to achieving better photoperiodic control is likely to require a change in spectral output rather than an increase in the number of lamps and light emitting diodes (LEDs) offered a potentially efficient alternative.

Therefore, the second stage of this project was designed to examine the suitability of LEDs as an energy-saving alternative to T in photoperiod manipulation. A range of important horticultural species have been tested for their response to night-break and day-extension lighting by two LED types;

i) Red (R), FR, mixtures of R and FR, and Blue (B) LED modules and

ii) FR only, Deep Red/White (DR/W), and Deep Red/White/Far-Red (DR/W/FR) LED flowering lamps in order to provide realistic recommendations for growers.

The R LEDs produced light between 600 nm and 700 nm, FR between 700 nm and 800 nm, and B between 400 nm and 500 nm. DR is enriched in the red part of the spectrum but has additional wavelengths.

Summary and Conclusions

In the first stage of the experiment the suitability of replacing T lamps with CF lamps to control the photoperiodic response in nine different species was examined by growing plants in a suite of automated daylength controlled chambers (see photograph) where plants were exposed to 8 hours of daylight (from 08:00 h to 16:00 h) and then automatically transferred into light-tight chambers where the daylength was manipulated using T or CF lamps, or kept dark in the case of the short day (SD) treatment. Different light levels (1, 2.5 and 5 µmol/m^2/s) were used in the chambers. The effect of light level was also examined on fixed benches using light gradients (0.3 to around 9.3 µmol/m^2/s) to extend the natural short daylengths over winter. Both 8-hour day-extension (DE) lighting from 16:00 to 24:00 h, and 4-hour night-breaks (NB) from 22:00 h to 02:00 h were tested.

For the second stage of the project the control of photoperiodic flowering responses to light-emitting diodes (LEDs) was investigated in order to compare the efficacy of replacing tungsten bulbs with LEDs. By using the same suite of automated day length controlled cabinets and the same SD control treatment this experiment provided comparable data for a similar range of horticultural species. In order to provide realistic recommendations for growers, commercially available lamps that have been developed for use in the horticultural industry were tested; i) Philips GreenPower LED modules, developed specifically for applications such as multilayer plant production, plant research and plant production in conditioned environments; ii) Philips GreenPower LED Flowering lamps, which have been specially developed as a replacement for the incandescent lamp to extend day length to control flowering.

NB and DE treatments within the photoperiod compartments consisted of either T lamps or LED modules with R, FR or B LEDs, or mixtures of R and FR at two different ratios (25%R+75%FR and 75%R+25%FR). T lamps were set to 2.5 µmol $m^{-2}s^{-1}$ and the LED modules were set to 2.5±1.5 µmol $m^{-2}s^{-1}$. Due to space restrictions B LEDs were only tested as a DE treatment. DE flowering responses to three types of LED flowering lamp were compared using the fixed benches. The three lamp types and the light levels tested were; FR, 0.8±0.2µmol $m^{-2}s^{-1}$; DR/W, 7.5±1µmol $m^{-2}s^{-1}$; and DR/W/FR, 3±0.9µmol $m^{-2}s^{-1}$.

Compact Fluorescent Lamps

Chrysanthemum (Tampico White) plants grown under an 8-hour daylength (SD) budded and flowered rapidly, while all of the DE and NB treatments remained vegetative until they had produced around 17-20 leaves on the side shoot; then they budded autonomously. Therefore, CF lamps would appear to be safe for chrysanthemum. Interestingly even plants exposed to very low light levels (0.3 to 1 µmol/m^2/s) remained vegetative, suggesting that this cultivar might be more sensitive to light when compared with some of the older cultivars which were tested previously at GCRI.

Poinsettia (Prestige Early Red) was also reasonably sensitive to CF lamps. The plants grown under short days soon went red and had cyathia, while all of the long-day treatments initially remained green. Plants were kept for 26 weeks from pinching and over time some of the DE and NB plants eventually showed some colour, although they did not develop fully red bract stars. There was considerable variability between plants, but colour was seen more frequently in the DE treatment with CF lamps. Plants appeared to be sensitive down to very low (0.3 µmol/m^2/s) light levels.

Non-stop begonia (Illumination Rose) also responded well to CF lamps, which were equally effective at delaying tuber formation and promoting shoot growth as T lamps. Plants appeared to be sensitive to very low (down to 0.3 µmol/m^2/s) light levels.

Christmas cactus (Olga) was the only SD species tested where CF lamps were less effective than T. Flowering of these plants had been delayed by a T DE treatment in commercial production before they were transferred to the experiments and this was also the most effective treatment for delaying flowering. T NB and CF NB and CF DE also all delayed flowering of Christmas cactus compared with the SD treatment.

Fuchsia (Patio Princess) plants grown under a continuous 8-hour daylength had no flower buds even at the end of the experiment (22 weeks after bud appearance in the long-day treatments) whereas the long day treatments budded rapidly. The DE treatment with CF lamps delayed flowering compared with the other long day treatments, but only by around 3 days. Plants appeared to be sensitive to very low (0.3 µmol/m^2/s) light levels.

CF lamps tended to be less effective than T lamps for most of the LDP that were tested. With **antirrhinum** (Bells Red), **lisianthus** (Florida Silver and Forever Blue) and **pansy** (Majestic Giant Purple), DE lighting with CF lamps proved ineffective, irrespective of the light level. NB lighting with CF lamps was more effective, although it did not tend to hasten flowering as much as a T NB. In the case of **antirrhinum** and **lisianthus**, plants budded sooner with an 8-hour T DE than they did with a 4-h T NB. Similar results were found across the light levels tested.

DE lighting with CF lamps hastened flowering of **petunia** (Express Salmon) when compared with the short day treatment. However, once again, these lamps were not as effective as T, especially when used as a DE. Similar results were found across the light levels tested.

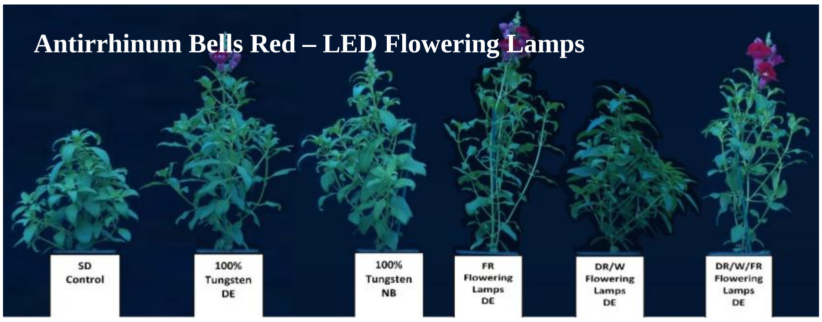
The first stage of this project concluded that there was no single CF solution that would have satisfied the needs of all species when replacing tungsten lighting to manipulate photoperiod. It had not been possible to generalise according to whether the crop had a SD or LD response.

LED Flowering Lamps

In the second stage of the project the DR/W/FR LED flowering lamps were able to control the flowering or tuber development of all of the species tested, with the exception of Christmas cactus (photographs of **chrysanthemum** and **antirrhinum** are shown below as examples of both a SD and a LD plant type and the full results summary is provided in the table below).

As for **chrysanthemum** (Tampico White) plants grown under a T DE or NB, those grown under DR/W/FR LED flowering lamps had not produced visible buds after 91 days in treatment and had produced 10-14 additional leaves on the most developed side shoot compared with those under SD conditions. Similarly, for **poinsettia** (Prestige Early Red), plants grown under T DE, NB or DR/W/FR LED flowering lamps had not developed red bracts 156 days into treatment. The tuber fresh weight of **begonia** (Illumination Rose) was reduced by 5.77g, for plants grown in the T DE treatment, and by 5.85g, for plants grown under DR/W/FR LED flowering lamps.

However, for **Christmas cactus** (olga) plants, all three of the LED flowering lamps tested, FR, DR/W and DR/W/FR, caused a delay in flowering equivalent to T NB but T DE resulted in an even greater delay.



Across the LD species tested, **antirrhinum** (Bells Red), **lisianthus** (Florida Silver), **pansy** (Majestic Giant Purple) and **petunia** (Express Salmon), an 8 hour day extension with DR/W/FR or FR LED flowering lamps provided a level of photoperiodic control equivalent to the 8 hour T DE treatment, which was more effective than the 4 hour T NB treatment for antirrhinum and petunia.

Chrysanthemum was the only species tested where the DR/W LED flowering lamp DE treatment was able to induce the same photoperiodic response as T (DE and NB); plants grown under these treatments had not produced visible buds after 91 days.

GreenPower flowering lamp types tested in eight-hour day-extension treatments

Plant species		Flowering lamp type		
		Far-red only	Red + white	Red + white + far-red
Long-day plants	Antirrhinum	✓	X	✓
	Lisianthus	✓	X	✓
	Pansy	✓	X	✓
	Petunia	✓	X	✓
Short-day plants	Begonia	X	X	✓
	Christmas cactus	X	X	X
	Chrysanthemum	X	✓	✓
	Poinsettia	X	X	✓

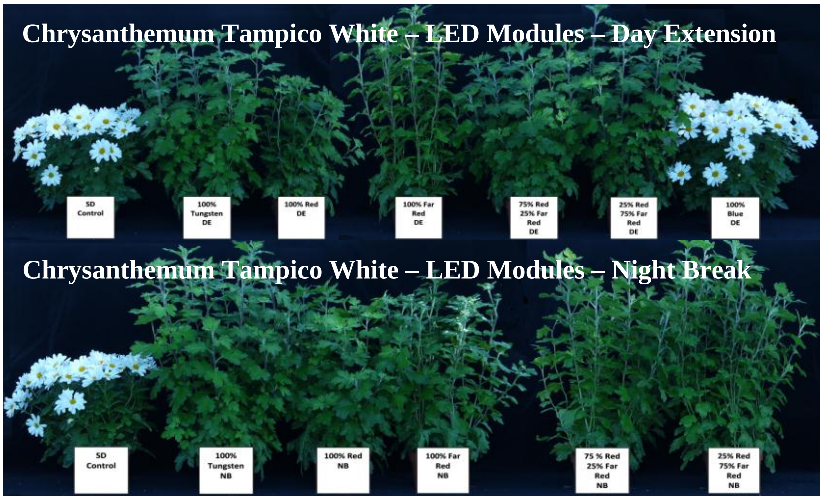
✓ = comparable response,   X = response is not as good as tungsten

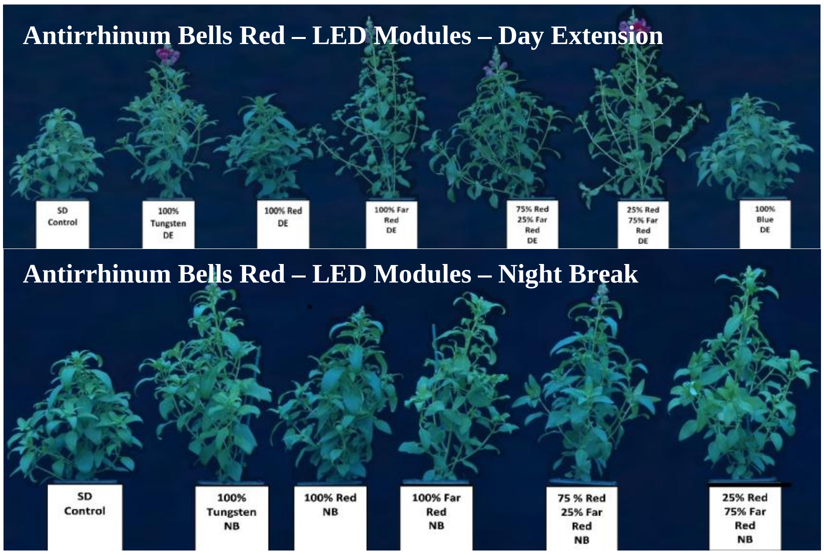
LED Modules

Generally, combinations of R (~660nm) and FR (~730nm) light were the most effective LED module treatments, as long day treatments delayed flowering in SD species and hastened flowering in LD species. However, which light quality and type of LD treatment was most effective varied between species and appears to be species specific (photographs of chrysanthemum and antirrhinum are shown below as examples of both a SD and LD plant type and the full results summary is provided in the table below).

The 100% B LED module DE treatment was generally ineffective across both SD and LD species. All of the SD species, **chrysanthemum**, **poinsettia**, **Christmas cactus** and **begonia**, showed no significant difference in flowering time or tuber development between the 100% B and SD treatments. Of the LD species; **lisianthus** and **petunia** showed no significant difference in flowering time between the 100% B and the SD treatments; for **antirrhinum** and **pansy** although there was a significant difference between the 100% B and the SD treatments, the 100% B LED module was among the least effective treatments for these species.

For **antirrhinum** (Bells Red), **lisianthus** (Florida Silver), **pansy** (Majestic Giant Purple) and **petunia** (Express Salmon) the response to 25%R+75%FR DE was equivalent to the most effective T treatment. Antirrhinum and petunia plants grown under T DE flowered earlier than those grown under T NB, similarly, the LED modules were more effective at hastening flowering as DE rather than NB treatments. Other LED module combinations were effective at hastening flowering for these four species, for example, 75%R+25%FR NB and 25%R+75%FR NB were equally as effective as 25%R+75%FR DE for pansy. Delayed SD responses were observed in **Chrysanthemum** (Tampico White), **begonia** (Illumination Rose) and **poinsettia** (Prestige Early Red) plants grown under 75%R+25%FR DE treatment; flowering or tuber development was equivalent to T DE and T NB treatments.





Although, 75%R+25%FR DE was a significantly effective long day treatment for delaying flowering in **Christmas cactus**, 25%R + 75%FR DE was equivalent to T DE (which was more effective than T NB).

A cautious approach should be taken with regards to the replacement of T with CF lamps as just over half of the species tested did not respond effectively to the light spectrum of CF lamps; the results observed applied even when the light level was increased to twice that of the current commercial norm. This is probably because CF lamps lack FR light, which appears to be more important for DE than NB lighting. Although CF lamps would provide a suitable replacement for T for some of the species tested (chrysanthemum, poinsettia, fuchsia and begonias), it would be more beneficial for growers to be able to use a single, more efficient alternative to T.

In considering the replacement of T lighting using LED flowering lamps, the DR/W/FR flowering lamps would be the most appropriate as they illicit the equivalent response to T in all species tested, with the exception of Christmas cactus. In the case of begonia, the fresh weight of the tubers produced was equivalent to that produced under T lighting. The FR flowering lamps provided good flowering control for half of the species tested, but had detrimental effects on plant height; increasing stretching in these species. The DR/W flowering lamp treatment was only able to provide an equivalent level of control for chrysanthemum, due to the lack of FR in the spectrum. For chrysanthemum, however, they would be a preferable choice over the DR/W/FR lamps as they caused less stretching (even in comparison to T).

Ratios of red and far-red LED light which generated a comparable photoperiod response to tungsten bulbs in day-extension (DE) and night-break (NB) treatments

Plant species		0% red + 100% far-red		25% red + 75% far-red		75% red + 25% far-red		100% red + 0% far-red	
		DE	NB	DE	NB	DE	NB	DE	NB
Long-day plants	Antirrhinum	✓	✓	✓	✓	✓	✓	X	x
	Lisianthus	✓	x	✓	✓	x	✓	X	x
	Pansy	x	x	✓	✓	x	✓	X	x
	Petunia	✓	x	✓	✓	✓	✓	X	x
Short-	Begonia	x	x	✓	✓	✓	✓	✓	✓

day plants	Christmas cactus	x	x	✓	✓	✓	✓	X	✓
	Chrysanthemum	x	x	✓	✓	✓	✓	✓	✓
	Poinsettia	x	x	x	✓	✓	✓	X	✓

✓= comparable response to tungsten,   X= response is not as good as tungsten

This project has demonstrated the importance of FR light in the control of flowering and considering the very low FR output of CF lamps and their inability to control flowering in over half of the species tested in the first stage of the project, they do not seem to be a dependable alternative to T. In the long term, LED lighting may well be the preferable alternative to T lighting because of the potential to adjust spectral output. LEDs have advanced greatly and are now relatively efficient and robust. They also have a much longer life expectancy than other lamp types, and this is not shortened by repeated cycling. While LEDs offer many advantages, high equipment cost is currently an issue, although this is likely to come down over time. LED lamps can be manufactured to give light of any given wavelength (colour), which is a big advantage for photoperiodic lighting if the plant requirements are known.

Financial benefits

As tungsten lamps are currently being phased out, growers face financial losses if they do not identify suitable alternatives. Implementing new lighting strategies is likely to result in capital costs, this project will assist in identifying strategies that are safe but not over-specified so that they do not incur more set up and running costs than necessary.

Capital costs are high for the installation of LEDs but as a new technology prices are widely expected to reduce with time and benefits include their efficiency coupled with their long operating life. The HDC project *PO 010: LED Lighting for Horticultural Applications – Establishing the Economics of Current Hardware Offerings* provides a current economic appraisal along with a calculator for growers to use for their own situation. It should also be noted that the Philips LED flowering lamps are able to fit into existing tungsten festoon lighting setups although they are only available in screw fittings. Companies are developing other LED systems, for example, SolarOasis have developed both the GrowStar Pro550 (a broad spectrum solid state LED plant grow light) and monochrome LED clusters (a research and development tool available in 22 wavelengths). As more LED systems become available there are likely to be significant reductions in cost.

Action Points

- Energy-saving compact fluorescent bulbs are only a suitable replacement for the control of flowering in half of the species tested in this project and given the low FR output of CF lamps they are unlikely to provide a dependable alternative to T lighting.
- DR/W/FR LED flowering lamps provided a similar level of flowering control as T day-extension treatments for all species tested, with the exception of Christmas cactus.
- A mixture of R and FR LED modules provided an equivalent level of flowering control to tungsten bulbs in most species tested. From the results obtained here a 75%R+25%FR LED module day-extension treatment would be recommended in order to provide effective photoperiodic control and to minimise stretching.
- It would be sensible for growers to test these and other suggested ratios of R+FR LED modules on a small scale with their own mix of varieties before implementing changes.
- This project has investigated the use of Philips GreenPower LED lighting, however, there are other, commercially available lighting systems that have not been tested here and therefore, may provide varying results.

SCIENCE SECTION

Introduction

Tungsten bulbs (T) have traditionally been used for day-extension and night-break lighting as they are cheap to purchase and are rich in red and far-red light. However, Defra announced a phase out of 'inefficient' tungsten bulbs over the period Jan 2008 to Dec 2011. Furthermore, there is a desire for some growers to move away from T lamps to minimise stretching due to the light quality. Consequently, there is an urgent need to assess the suitability of alternative lamps so that clear recommendations can be made for their use.

It has been expected that tungsten lamps will largely be replaced with compact fluorescent lamps (CF), however, lamps that are sold as '60W equivalent' may be equivalent to a 60W tungsten bulb in terms of what the human eye perceives (lux), but they are not equivalent for plants. A number of HDC projects (e.g. PC 238 and PC 246) have used compact fluorescent lamps for day-extension and night-break lighting, without promoting a flowering response in what were thought to be long-day species.

The first stage of this project (2009-2010) examined the suitability of CF lamps for daylength control by investigating the flowering responses of a range of horticultural species to light quality and quantity (See PC296 Interim report 2010). Flowering and/or tuber formation was controlled as well by CF lighting as they were by T lighting for chrysanthemum, poinsettia, begonia and fuchsia but not for antirrhinum, Christmas cactus, lisianthus, pansy and petunia. Therefore, for over half of the species, CF lamps did not match the light spectrum from T lamps well enough to control flowering effectively. Where CF lamps were not effective, increasing the light level up to 9.3 µmol $m^{-2}s^{-1}$ was not sufficient to improve response. Christmas cactus was the only species which appeared to be influenced by light level with a decrease in delay of flowering when the CF or T intensity was below 1 µmol $m^{-2}s^{-1}$. As CF lamps lack far-red light, the solution to achieving better photoperiodic control is likely to require a change in spectral output rather than an increase in number.

Light quality was the dominant factor in the initial experiments and therefore, for the second stage of the project the control of photoperiodic flowering responses to light-emitting diodes (LEDs) was investigated in order to compare the efficacy of replacing tungsten bulbs with either LEDs or CF lamps. By using the same suite of automated day length controlled cabinets this experiment provided comparable data for a similar range of horticultural species. In order to provide realistic recommendations for growers, commercially available lamps that have been developed for use in the horticultural industry were tested; i)Philips GreenPower LED modules, developed specifically for applications such as multilayer plant production, plant research and plant production in conditioned environments; ii) Philips GreenPower LED Flowering lamps, which have been specially developed as a replacement for the incandescent lamp to extend day length to control flowering.

The application of LEDs in horticulture has been restricted predominantly to research due to the high cost involved however, as they become more common in a variety of applications it is likely that there will be a significant decrease in cost. In comparison to existing horticultural lighting, LEDs offer several substantial advantages; principally, the ability to control their spectral composition for photoperiodic lighting especially if the particular light requirements of a plant species are known. LEDs produce very high light levels but with low radiant heat output, which means that they can be operated in close proximity to the plant tissue. They also have a much longer life expectancy, maintaining a useful light output for years without replacement (expectancy is not shortened with repeated cycling). The light intensity and quality are adjustable and so can simulate the changes of sunlight intensity during the day and they can be easily integrated into digital control systems, for facilitating special lighting programs.

This project aims to examine the suitability of LEDs as an energy-saving alternative to T in photoperiod manipulation. As it is anticipated that a combination of red (~660nm) and far-red (~730nm) light will probably give a good response for most species, a range of important horticultural species are being tested for their response to night-break and day-extension lighting by two LED types; Red, Far-Red, mixtures of red and far-red and Blue LED modules and Far-Red, Deep Red/White and Deep Red/White/Far-Red LED flowering lamps.

This report summarises the response of a range of horticultural species to long day (LD) lighting, provided by CF and LED lamps in comparison to T lighting. The data collected indicates the importance of light quality and suggests that by manipulating spectral output through the use of different LEDs, plant responses can be controlled as effectively as with tungsten lighting.

Materials and Methods

Treatments

The influence of light quality was assessed by examining the response to day extension (DE) or night break (NB) lighting provided by either Philips GreenPower LED modules or Philips GreenPower LED flowering lamps of varied spectral output in comparison to T lamps.

Plant response to T lamps and Philips GreenPower LED modules was assessed by growing plants on trolleys in natural daylight in three glasshouse compartments between 08:00 h and 16:00 h GMT with plants transferred to light-tight photoperiod cabinets outside of these hours; the experiment spanned the period November to March 2011/12. Plants were exposed to long day (LD) lighting inside the cabinets either via a NB from 22:00 h to 02:00 h or as a DE from 16:00 h to 24:00 h daily. Cabinets were actively vented when closed to maintain temperatures equivalent to the glasshouse compartment.

NB and DE treatments within the photoperiod compartments consisted of either T lamps or Philips GreenPower LED modules with red (R), far-red (FR) or blue (B) LEDs, or mixtures of red and far-red at two different ratios (25%R+75%FR and 75%R+25%FR). T lamps were set to 2.5 µmol $m^{-2}s^{-1}$ and the LED modules were set to 2.5±1.5 µmol $m^{-2}s^{-1}$. The compartments contained combinations of R, FR or B LED modules as detailed in Table 1. Due to space restrictions B LEDs were only tested as a DE treatment. The control, short day (SD), treatments consisted of a cabinet which was closed but not lit, therefore the plants were only exposed to the 8h natural SD when outside the compartment (Figure 1).

Table 1. Summary of Philips GreenPower LED module combinations used and their respective spectral outputs.

Lamp	Spectral Composition	Treatment	Light Levels (µmol $m^{-2}s^{-1}$) 320-500nm	600-680nm	680-800nm	400-800nm
None (Short Days – SD)		SD	-	-	-	-
Tungsten (Long Days – LD)		DE	0.2	1.1	1.4	2.5
	Red	DE	-	2.4	-	2.4
	Far-Red	DE	-	-	3.2	3.2
Philips GreenPower LED Modules	75% Red + 25% Far-Red	DE	-	1.8	0.7	2.5
(Long Days – LD)	25% Red + 75% Far-Red	DE	-	0.5	2.6	3.1
	Blue	DE	1.1	-	-	1.1
Tungsten (Long Days – LD)		NB	0.3	1.2	1.3	2.5
Philips GreenPower	Red	NB	-	2.4		2.4
LED Modules	Far-Red	NB	-	-	3.8	3.8
(Long Days – LD)	75% Red + 25% Far-	NB	-	1.5	0.3	1.8

	Red 25% Red + 75% Far-Red	NB	-	0.6	2.3	2.9

In addition to the LED modules tested in photoperiod cabinets, DE flowering responses to three types of Philips GreenPower LED flowering lamp were compared. The three lamp types and the light levels tested were; Far-Red only (FR), 0.8±0.2µmol $m^{-2}s^{-1}$; Deep Red and White (DR/W), 7.5±1µmol $m^{-2}s^{-1}$; and Deep Red, White and Far-Red (DR/W/FR), 3±0.9µmol $m^{-2}s^{-1}$. For these experiments, a festoon was suspended above each bench with equal lamp spacing along the length of the bench in order to deliver an even light level distribution (Figure 1).

R LEDs produce light between 600 nm and 700 nm, FR between 700 nm and 800 nm, and B between 400 nm and 500 nm. DR is enriched in the red part of the spectrum but has additional wavelengths. The spectra for each of the individual LED treatments were obtained using a fibre optic spectrometer (StellarNet Inc EPP2000); data is commercially sensitive and is held in a confidential annex to this report.

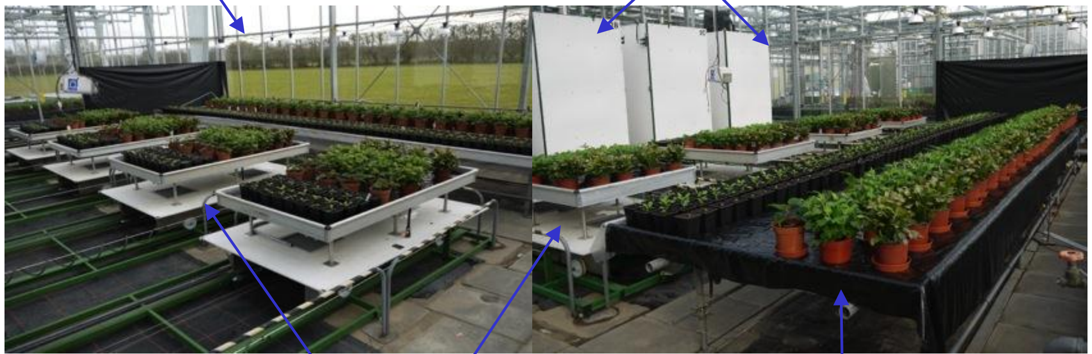
The different LED flowering lamp types were compared using benches housed in separate glasshouse compartments and screens were used where required to eliminate light spill between treatments. The LED flowering lamps delivered a DE from 16:00h until 24:00h.

A summary of the experimental layout is given in figure 1.

Compartment 1					Compartment 2					Compartment 3				
Door	**25% Red + 75% Far-Red NB**	**75% Red + 25% Far-Red NB**	**Far-Red NB**	**Red NB**	Door	**T NB**	**SD**	**Blue DE**	**T DE**	Door	**25% Red + 75% Far-Red DE**	**75% Red + 25% Far-Red DE**	**Far-Red DE**	**Red DE**
LED Flowering Lamps: Deep Red, White and Far-Red (DR/W/FR)					**LED Flowering Lamps: Deep Red and White (DR/W)**					**LED Flowering Lamps: Far-Red (FR)**				

Festoons above benches fitted with Philips GreenPower LED flowering lamps

Photoperiod Chambers fitted with Philips GreenPower LED modules



Automated trolleys; exposing plants to 8h natural daylight in the glasshouse and long day lighting inside the photoperiod chambers

Stationary Bench

Figure 1. Experimental Layout.
Schematic diagram (above) – arrangement of lighting treatments; photoperiod chambers shaded green and stationary benches shaded red.
Photographs (left) – glasshouse experimental setup.

Plant raising

The species tested were chosen to include both LD and SD response types with cultivars reflecting current commercial selections. In order to maintain consistency with the first stage of the project, which compared the control of flowering by T and CF lamps, the same nine species were used. Where possible, the seed, rooted and unrooted cuttings and part grown plants were also obtained from the same sources. This was possible for all but the Begonia, which were obtained as seed from Ball Colegrave instead of part grown plugs from Bordon Hill Nursery. Plants were either raised from seed, or from rooted or unrooted cuttings, according to standard practise and availability of young plants, Christmas cactus plants were partially raised on a commercial nursery before being transferred to the experiment. Plants were maintained in non-inductive conditions prior to starting treatments.

Species	**Cultivar**	**LDP/ SDP**	**Source**	**Date into treatment**
Antirrhinum	Bells Red	LDP	Goldsmith Seeds (seed)	01/11/2011
Begonia	Illumination Rose		Ball Colegrave (seed)	01/11/2011
Christmas cactus	Olga	SDP	Opperman Plants (as part grown plants)	01/11/2011
Chrysanthemum	Tampico White	SDP	Yoder Toddington (unrooted cuttings)	14/12/2011
Fuchsia	Patio Princess	LDP	Botany Bay Nurseries via Young Plants (rooted cuttings)	01/11/2011
Lisianthus	Florida Silver	LDP	Pan American (seed)	01/11/2011
Pansy	Majestic Giant Purple	LDP	Sakata (seed)	01/11/2011
Petunia	Express Salmon	LDP	Ball Colegrave (seed)	01/11/2011
Poinsettia	Prestige Early Red	SDP	Ecke Europe (rooted cuttings)	01/11/2011

All plants potted at Warwick University (Wellesbourne Campus) were grown in pots using Levingtons M2 compost mixed with Intercept when in treatments. Christmas cacti were potted in a specialist peat / perlite mix supplied by Bulrush to Opperman plants (Bulrush Schlumbergia). Prior to starting the treatments, the way in which the plants were raised varied depending on the species:

Antirrhinum, pansy and petunia seed were sown at Warwick University in 286 plug trays with Scotts Levingtons F2s compost in week 39. The trays were placed inside plastic bags, to maintain humidity, and germinated in Sanyo cabinets at 22°C with continuous light. Plastic bags were removed after emergence and after 10 days the trays were moved to a glasshouse compartment with temperature settings 17°C day and night with venting at +2°C, under natural daylight with blackouts set to start at 18:00 until 08:00hrs.

Begonia and lisianthus seed were sown at Warwick University in 286 plug trays with Scotts Levingtons F2s compost in weeks 35 and 37, respectively. The trays were placed inside plastic bags, to maintain humidity, and germinated in Sanyo cabinets at 22°C in 8 hour short day (SD) conditions. Plastic bags were removed after emergence and after approximately 30 days, the trays were moved to a glasshouse compartment with temperature settings 17°C day and night with venting at +2°C, under natural daylight with blackouts set to start at 18:00 until 08:00hrs.

On receipt in week 41, fuchsias were potted into 9cm pots with Levington M2 compost. They were placed onto capillary matting in a glasshouse compartment with temperature settings 17°C day and night with venting at +2°C, under natural daylight with blackouts set to start at 18:00 until 08:00hrs. Despite being kept in non-inductive SD conditions at Warwick University they began to flower in week 44, presumably because they had been exposed to inductive LD conditions at the nursery prior to delivery. These were not used further in the experiment.

Christmas cacti were received potted in week 41 as part grown plants. The plants were grown on in a glasshouse compartment with temperature settings 17°C day and night with venting at +2°C and night break lighting set to start at 22:00 until 03:15hrs, on for 15 minutes every half hour, using 100W tungsten lamps. In addition, supplementary lighting was set to start at 01:00 to 17:00hrs, using 400W high pressure sodium SON/T lamps (radiation limit set to 300 W/m^2).

Poinsettias were received as rooted cuttings in week 41. They were potted up in 13cm pots with Levington M2 compost mixed with Intercept and grown on in a glasshouse compartment with temperature settings 17°C day and night with venting at +2°C and night break lighting set to start at 22:00 until 03:15hrs, on for 15 minutes every half hour, using 100W tungsten lamps. In addition, supplementary lighting was set to start at 01:00 to 17:00hrs, using 400W high pressure sodium SON/T lamps (radiation limit set to 300 W/m^2).

Unrooted chrysanthemum cuttings were struck 5 per 14D pot in week 47, with Levington M2 compost mixed with Intercept. Cuttings were sprayed with Rovral (0.67 g/L) and covered with polythene after sticking. The glasshouse compartment had temperature settings 18°C day and night with venting at 24°C and cyclic lighting used from 23:00 until 04:15hrs with 15 minutes on and 15 minutes off. After 9 days the polythene sheets were removed and supplementary lighting was set to start at 01:00 to 17:00hrs, using 400W high pressure sodium SON/T lamps (radiation limit set to 300 W/m^2).

When plants were moved into treatments all glasshouse compartments were set to heat at 17°C day and night with venting at +2°C.

Species were arranged in rows on trolleys and benches so as to minimise competition between the contrasting plant sizes. Eight pots per species were placed on each trolley for the photoperiod cabinets. Approximately 25 pots of Poinsettia, Chrysanthemum and Christmas cactus and 40 pots of the other species were placed on each bench as illustrated in figures 2 and 3.

Pots were irrigated using capillary matting with applications tailored to the demands of each species as much as possible, except for Christmas cactus and Poinsettia, which were placed on saucers. All species were fed with Peters Excel 15:5:15 Cal-Mag (with N at 100 g/l in the dilute feed).

Pest control was via a preventative programme of biologicals (Encarsia, Eretmocerus, Aphidius, Phytoseiulus, and Amblyseius) in addition to the Intercept included in the growing medium. Other disease controls and insecticides were applied as needed rather than as a preventative programme. No growth regulators were used to ensure no interaction with the photomorphogenic responses of the plants to the daylength treatments.

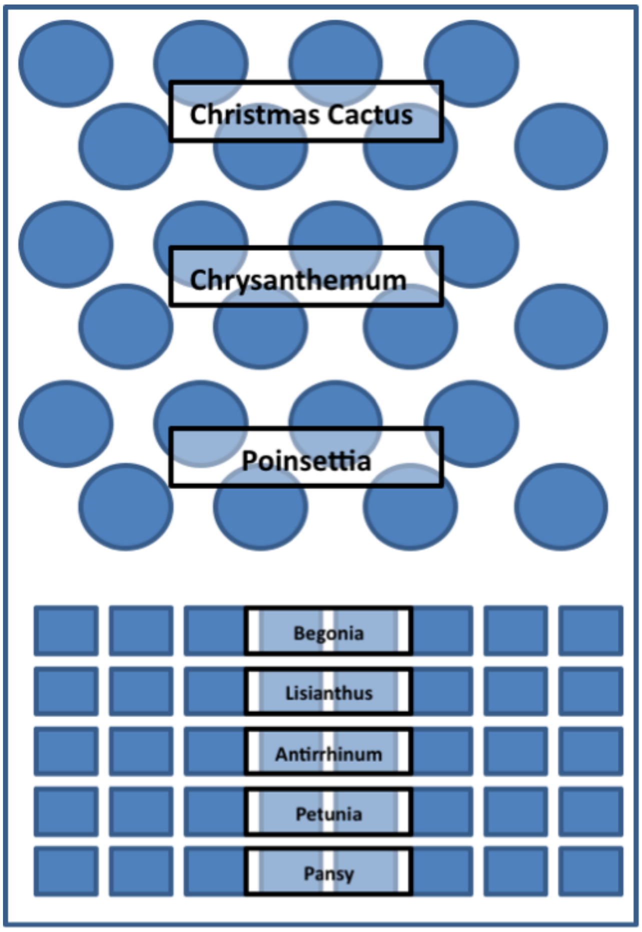


Figure 2. Plant layout for automated trolleys/photoperiod chambers, illuminated by Philips GreenPower LED modules.

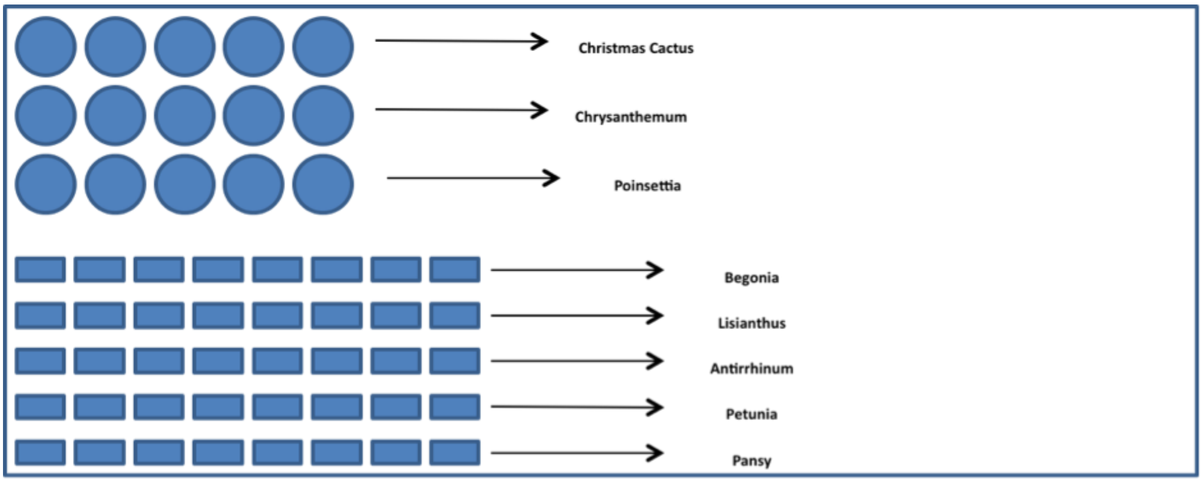


Figure 3. Plant layout plan for stationary benches, illuminated by Philips GreenPower LED flowering lamps).

Recording plant response:

Response to treatment was recorded through regular visual checks on plants. Once flowering became apparent through the appearance of visual buds, formal inspections commenced for that species with records taken three times a week with date of first visible bud per plant and first open flower per plant being recorded.

For some species, the appearance of buds and then flowers was not an appropriate measure of the effects of the LD treatments. In the cases below, the following data were recorded:

Poinsettia: date of first bract / leaf reddening and first visible cyathia.

Chrysanthemum: date of first visible bud plus leaf number beneath the first visible bud to the node above the main stem.

Begonia: date of first visible bud was recorded and tuber formation was evaluated by destructive samples taken at the end of the experiment (09/03/12 and 10/03/12). All 8 samples from each trolley and 20 samples from each bench were assessed for number of leaves greater than 2cm, plant fresh weight (i.e leaves plus tubers with fine roots removed), tuber fresh weight, plant dry weight (minus tubers) and tuber diameter.

Photographs in appendix I illustrate how the stages recorded were defined for each species.

Glasshouse environmental data:

Air temperature, RH, vent opening and pipe temperatures were collated from the Priva data storage system. Air temperature and RH were also logged using independent sensors within the main glasshouse compartment and in each photoperiod cabinet. Set points were adjusted to ensure consistency of average achieved temperature in each glasshouse. Light sensors were also used to monitor the DE and NB treatments and daily light intensities on the benches. Weekly checks also used to check for and replace any dead bulbs.

A photographic record of treatments was also kept.

Results

Given the layout of the experiment, two analysis of variance tests were used to analyse the photoperiod cabinet data and the separate stationary bench experiments. One test compared the photoperiod cabinet data i.e. all Philips GreenPower LED modules (DE and NB) with T DE, T NB and SD control. The other compared the Philips GreenPower LED flowering lamp DE treatments, delivered on stationary benches, with T DE, T NB and SD control (photoperiod cabinet data). Therefore, to avoid confusion, the results for the LED modules and the LED flowering lamps (for which only DE treatments were tested) are presented separately for each species tested. Standard Errors (SE) of individual means are plotted on the bar charts representing each treatment, which provides an indication of the variability of all data included. Significance is expressed where probabilities resulting from analyses are at the <0.05 level and least significant differences (LSD) are recorded in figure legends.

Antirrhinum Bells Red

Previous experiments have shown that for antirrhinum, the light spectrum from CF lamps did not match that from T lamps well enough to control flowering effectively. When compared with the SD treatment, Tungsten NB and DE significantly hastened the appearance of first visible buds, whereas CF treatments statistically had no effect. Therefore, delivering LD treatments with CF lamps was ineffective for antirrhinum.

Philips GreenPower LED modules

Development of visible buds

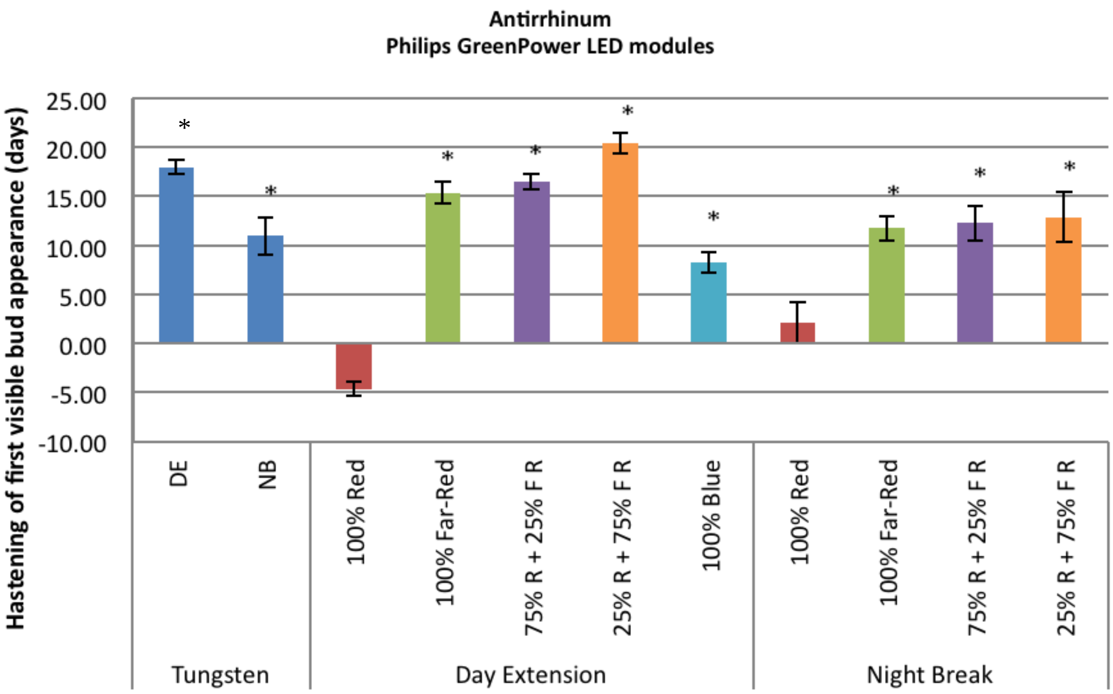


Figure 4. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB treatment, on the hastening of first visible bud appearance relative to the short day control, which has been set to 0. Negative numbers indicate where the lighting treatments delayed bud appearance. Error bars represent SE, LSD = 4.04 and * denotes a significant effect of light treatment on plant response.

Both T NB and DE significantly (P<0.05) hastened the appearance of first visible buds compared with the SD treatment, which developed buds after 48 days (figure 4). As observed previously, T was more effective as a DE than a NB treatment for Antirrhinum. The

100% R LD treatments were statistically no different to the SD treatment, proving ineffective at hastening the appearance of buds.

The long day LED module treatments containing FR light were all effective (P<0.05) at hastening initiation with combinations of R and FR proving to be the most effective; NB treatments with FR, 75%R-25%FR and 25%R-75%FR lighting produced buds after 36.4, 35.9 and 35.3 days, respectively, which is comparable to the 37.1 days for T NB. The LED module DE treatments, with the exception of 100% R, proved more effective than T and LED NB treatments. The most effective treatment for antirrhinum relative to the SD control is 25%R-75%FR DE, which developed buds after 27.8 days, 2 days earlier than T DE. The B LED modules (tested as a DE treatment) were the least effective, hastening flowering by an average of 8 days.

Development of flowers from first visible bud

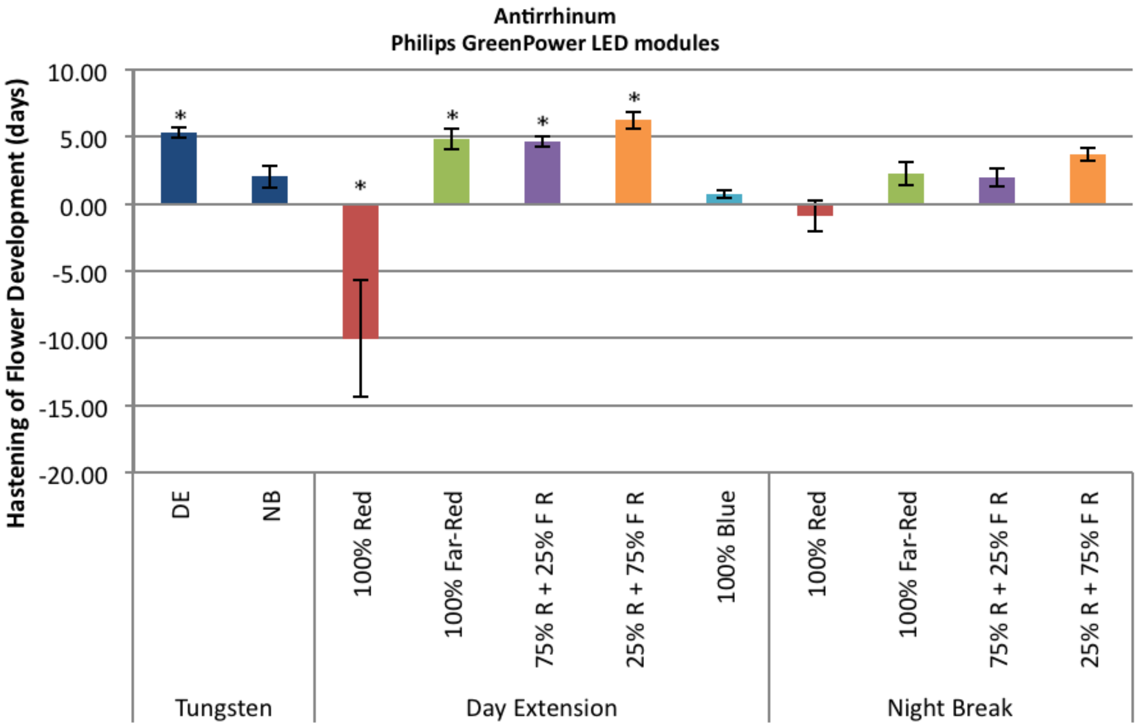


Figure 5. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB, on number of days from bud to flower relative to the short day control, which has been set to 0. Negative numbers indicate where the lighting treatments delayed flower development. Error bars represent SE, LSD = 4.06 and * denotes a significant effect of light treatment on plant response.

The time taken for buds to develop into flowers in each of the LD treatments was also assessed (figure 5). For the SD control, flowers developed from the first visible bud in an average of 29 days. Flower development under T NB was statistically no different to the SD control; however, T DE hastened flower development by 5 days.

Statistically, none of the NB treatments had a significant influence over the time taken for buds to develop into flowers compared with the SD control. The DE treatments had a greater effect. The 100% R DE treatment shows a significant delay of 10 days for the development of flowers from buds, whereas, the LED DE treatments containing far-red light hastened flower development by 4-6 days, with 25%R-75%FR DE hastening flower development by 6.25 days, a greater influence than T DE.

Philips GreenPower LED Flowering Lamps

Development of visible buds

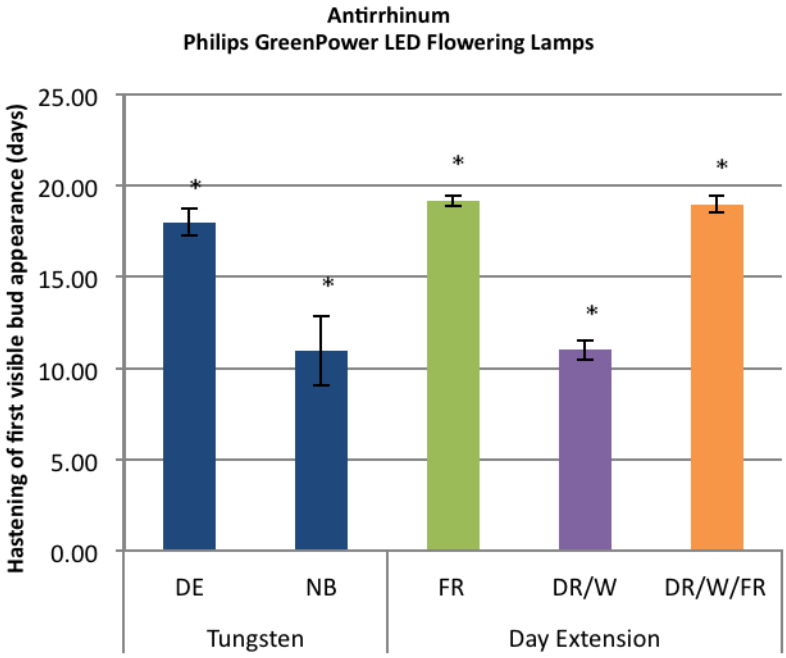


Figure 6. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on the hastening of first visible bud appearance relative to the short day control, which has been set to 0. Error bars represent SE, LSD (T) = 2.44/ LSD (LED Flowering Lamps) = 1.89 and * denotes a significant effect of light treatment on plant response.

The data obtained from the photoperiod chambers indicates a significant contribution of FR light to the hastening of bud development in antirrhinum, which is supported by the experiments carried out on the stationary benches using LED flowering lamps (figure 6). The SD control, T DE and T NB from the photoperiod chamber experiments are used here as controls to relate to the flowering lamp DE treatments.

The FR and DR/W/FR DE treatments are able to significantly (P<0.05) hasten the appearance of visible buds, on average developing buds 29 days into treatment, and thus 18-19 days earlier than the SD control, which is as effective as the T DE treatment. The DR/W DE treatment hastened the appearance of visible buds by 11 days, although not as effective as T DE, this flowering lamp is equally as effective as T NB, which also hastened bud development by 11 days.

Development of flowers from first visible bud

For the LED flowering lamps the time taken for first bud to develop into a flower is influenced in much the same way as for the appearance of first visible bud. Statistically, all LD treatments have a significant effect on flower development. FR and DR/W/FR DE treatments hasten flower development by approximately 7 days relative to the SD control, which is comparable to T DE (figure 7).

As with the hastening of bud appearance, T NB and DR/W DE treatments have a similar influence over the time taken for buds to develop into flowers relative to the SD control, hastening flower development by 2.1 and 1.5 days respectively.

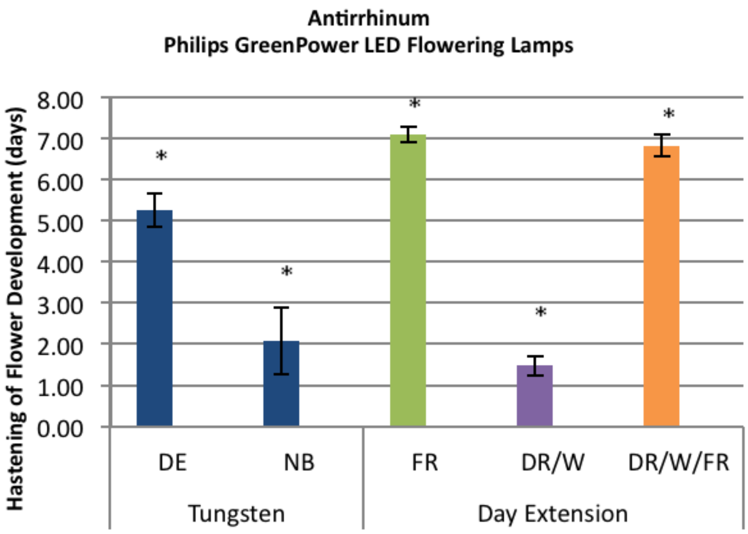


Figure 7. Comparing the effect of tungsten lamps (day extension or night break long day treatment) with Philips GreenPower LED flowering lamps (DE treatment), on number of days from bud to flower, relative to the short day control, which has been set to 0. Error bars represent SE, LSD (T) = 1.44/ LSD (LED Flowering Lamps) = 1.11 and * denotes a significant effect of light treatment on plant response.

Plant Height

Significant developmental and morphological differences were observed between the treatments. The effect of LED type on plant height was assessed relative to the SD control (figure 8). Plants under FR and 25%R-75%FR LD treatments were significantly taller than those under SD treatment, whereas, the R DE treatment produced plants that were significantly shorter. The T DE treatment did not have a significant impact on plant height; however, T NB treatment caused an increase in plant height of 3.5cm.

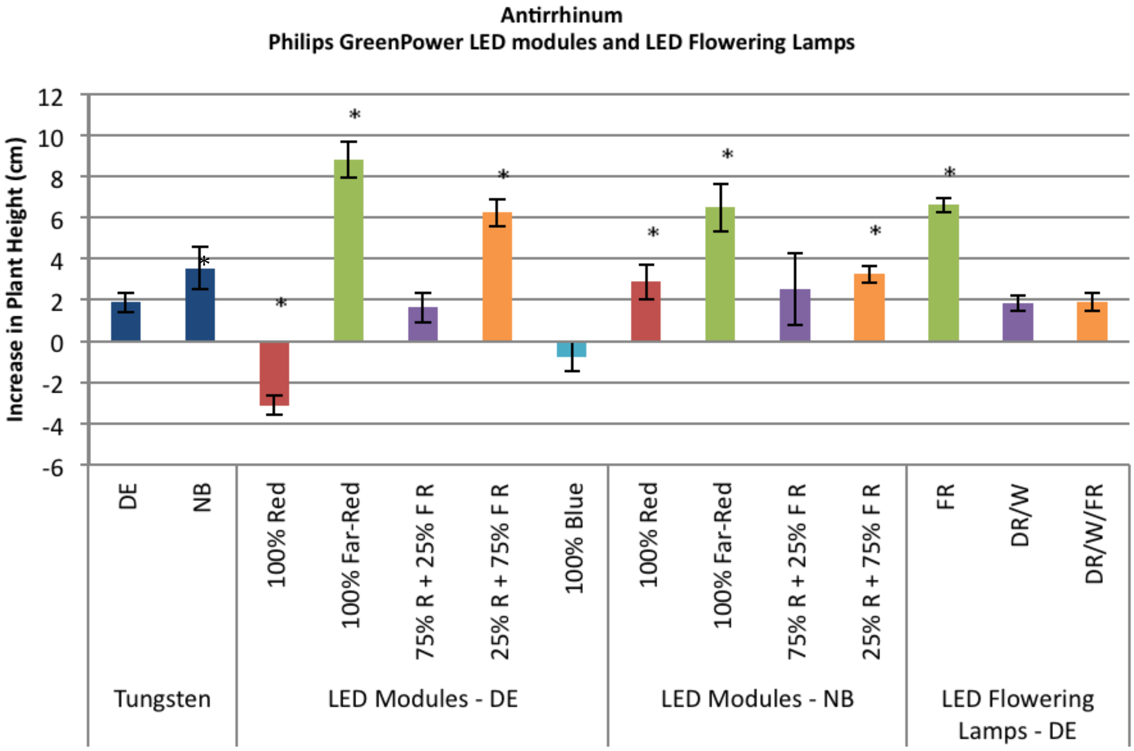


Figure 8. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE) and Philips GreenPower LED modules (DE or NB), on plant height relative to the short day control, which has been set to 0. Negative numbers indicate where the lighting treatments resulted in a decrease in plant height. Error bars represent SE, LSD (LED Modules and T) = 2.49/ LSD (LED Flowering Lamps) = 1.93 and * denotes a significant effect of light treatment on plant response.

Visual summaries of the effect of LED module, LED flowering lamp and T LD treatments relative to the SD control, which flowered on average 77 days into treatment, are presented in figures 9, 10 and 11. Comparing DE treatments from LED modules, both T and 25%R-75%FR were the most effective at hastening flowering of antirrhinum, with 75%R-25%FR and FR flowering slightly later (figure 9). For the NB treatments 75%R-25%FR and FR were slightly more effective at hastening flowering than T (figure 10). Comparing DE treatments given by LED flowering lamps, FR, DR/W/FR and T were equally as effective at hastening flowering (figure 11). With both LED modules and LED flowering lamps, LD treatments containing far-red light have been more effective at hastening flowering than those containing only R, B or DR/W.

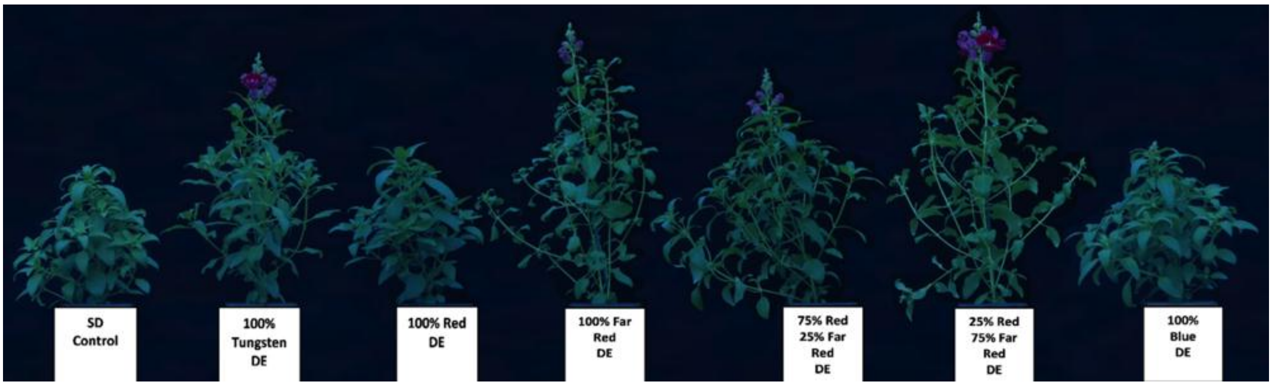


Figure 9. Antirrhinum: The effect of DE lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

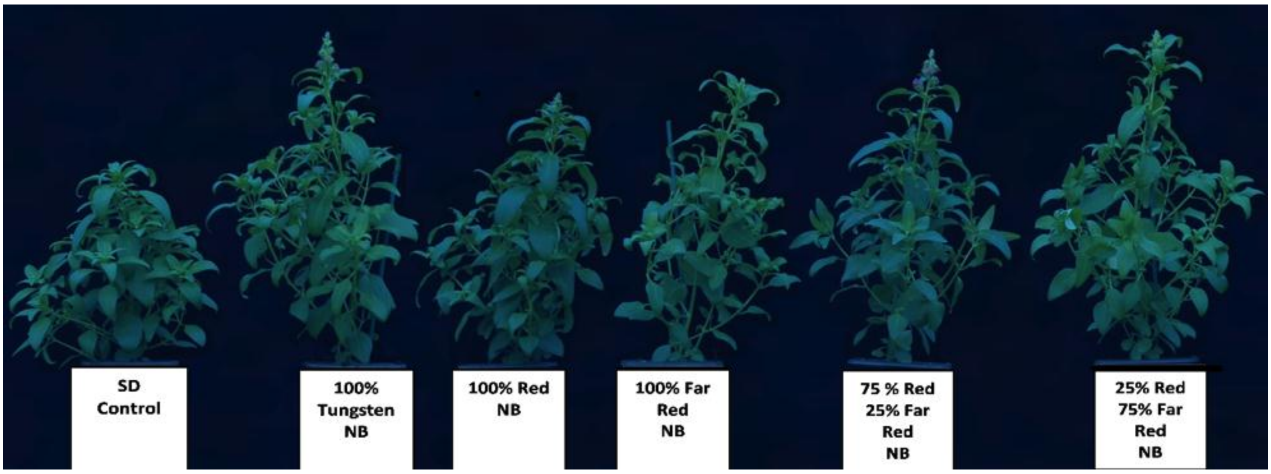


Figure 10. Antirrhinum: The effect of NB lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

Figure 11. Antirrhinum: The effect of DE lighting with different types of Philips GreenPower LED flowering lamps in comparison to T lamps (DE and NB) and a SD control.

Begonia Illumination Rose

The first experiment concluded that tuber formation in begonia was delayed and shoot growth was promoted as effectively by CF lamps as by T lamps. The evaluation of treatments focused on the size of tubers developed and overall plant size, which were assessed 64 days after the start of treatments. Here, begonias were grown from seed and destructively sampled 129 days after the start of treatments. In addition, the date of first visible bud per plant was recorded.

Philips GreenPower LED modules

Tuber development and plant size

Due to extensive sciarid fly damage, plants grown in SD conditions were disposed of 76 days into treatment. Prior to this, plants grown in SD conditions were developing similarly to the 100% B LED module treatment. For many of the species tested there has been no significant ($p<0.05$) difference between SD and 100% B LED module treatments, therefore, in the absence of SD control plants, the B LED treatment has been used as the control treatment.

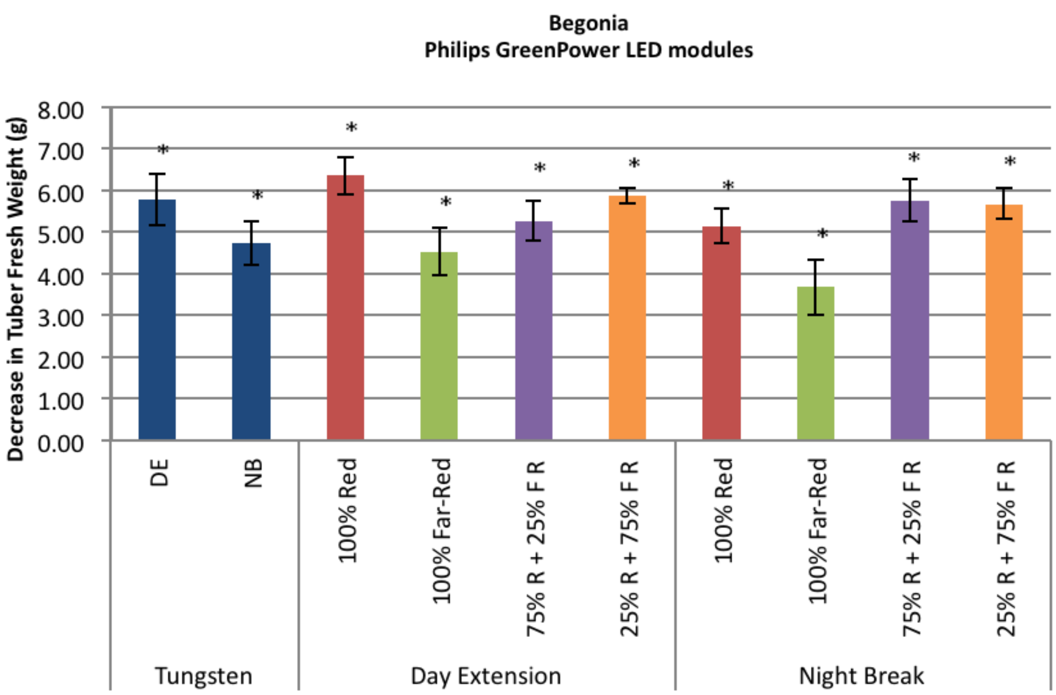


Figure 12. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using DE or NB treatment, on decreasing tuber fresh weight (g) relative to the 100% B LED treatment, which has been set to 0. Error bars represent SE, LSD = 1.43 and * denotes a significant effect of light treatment on plant response.

All LED module treatments significantly ($p<0.05$) reduced the fresh weight of tubers by 3-6g, equivalent to a 33-66% reduction of the fresh weight of tubers produced by the 100% B treatment, which was on average 9.01g (figure 12). 100%R and R+FR LED treatments had a comparable impact on tuber fresh weight, reducing tuber fresh weight by 5.14-6.35g, which is comparable to the response to T treatments. These treatments were more effective at decreasing tuber fresh weight than FR only treatments, with 100% FR NB being significantly less effective than 100% R DE.

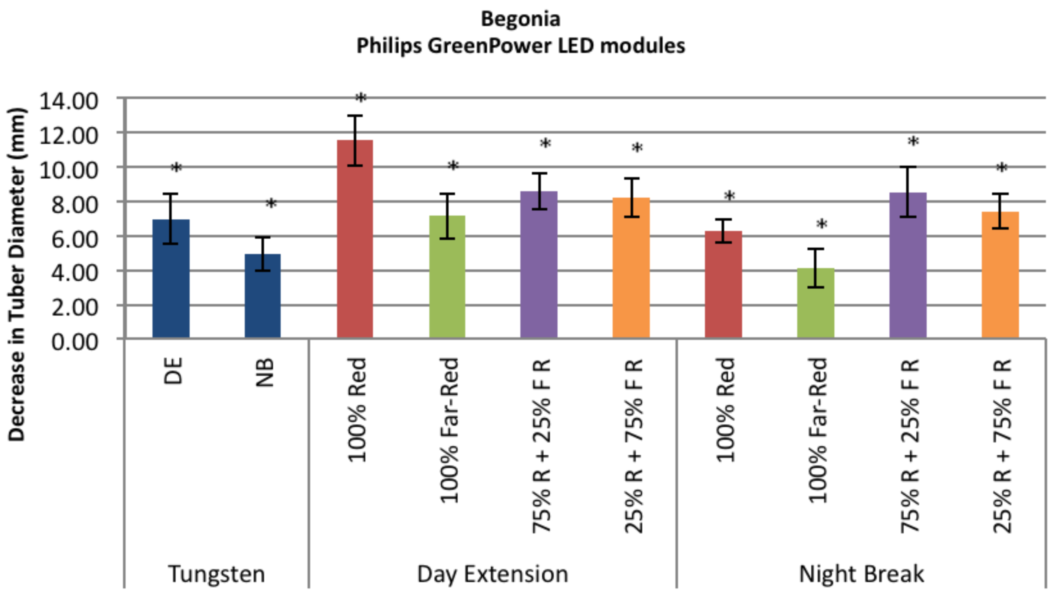


Figure 13. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB treatment, on decreasing tuber diameter (mm) relative to the 100% B LED treatment, which has been set to 0. Error bars represent SE, LSD = 3.28 and * denotes a significant effect of light treatment on plant response.

As with tuber fresh weight, all LD treatments tested, significantly decreased tuber diameter relative to the 100% B LED treatment, which had an average diameter of 25.05mm (figure 13). 100% R DE is the most effective treatment, decreasing tuber diameter by 11.54mm, which is significantly more effective than T DE and T NB. Statistically, both DE and NB 75%R+25%FR treatments are as effective as 100% R DE. Tuber diameters from plants grown under 25%R+75%FR DE and NB and 75%R+25%FR DE and NB treatments are comparable with T DE, decreasing tuber diameter by 7.42 – 8.55 mm.

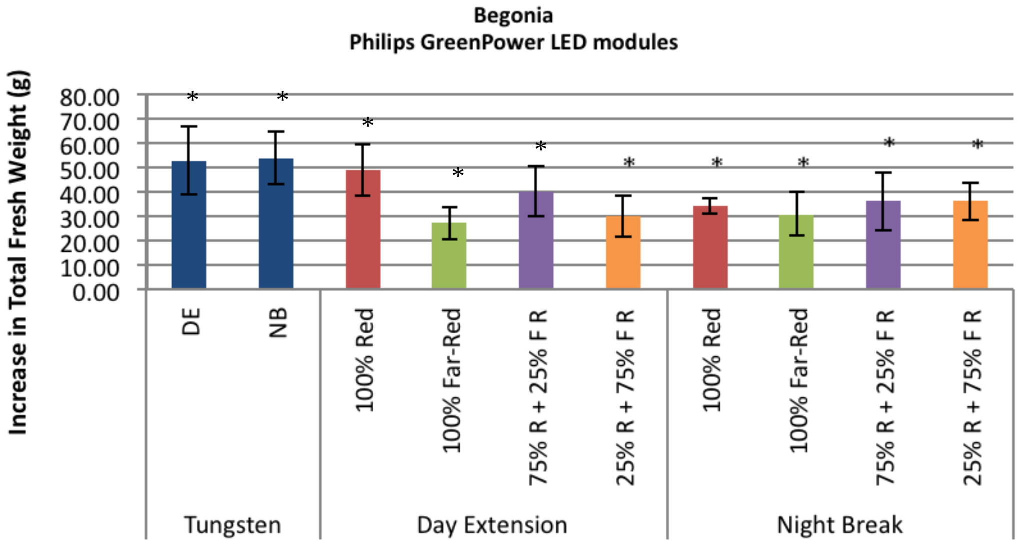


Figure 14. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB, on increasing total fresh weight (g) relative to the 100% B LED treatment, which has been set to 0. Error bars represent SE, LSD = 26.93 and * denotes a significant effect of light treatment on plant response.

In contrast to tuber formation, LD treatments increased overall plant size by an average of 35.6-62.6g per plant relative to the 16.37g average total fresh weight of plants grown in the 100% B LED treatment (figure 14). The 100% R LED treatment is the most effective LED treatment and is comparable to the T DE and T NB treatments, increasing total fresh weight on average by 57.8-62.6g. The total fresh weight data was very variable between plants within the same treatment and was not significantly influenced by LED type or LD treatment.

Development of visible buds

All LD treatments (both LED modules and T) significantly hastened the appearance of visible buds relative to the 100% B LED module treatment (figure 15). Begonia plants from all LED and T treatments were destructively sampled 129 days into treatment, at this stage the plants in the 100% B LED treatment had not produced visible buds and therefore, the actual values for the hastening of bud appearance will be greater than that shown here. All long day LED treatments hastened bud appearance by an average of 35-42 days, comparable to the 37-38 days by which T DE and T NB hastened bud appearance. N.B Due to the project timescale flowering data was not collected for begonia (Illumination Rose).

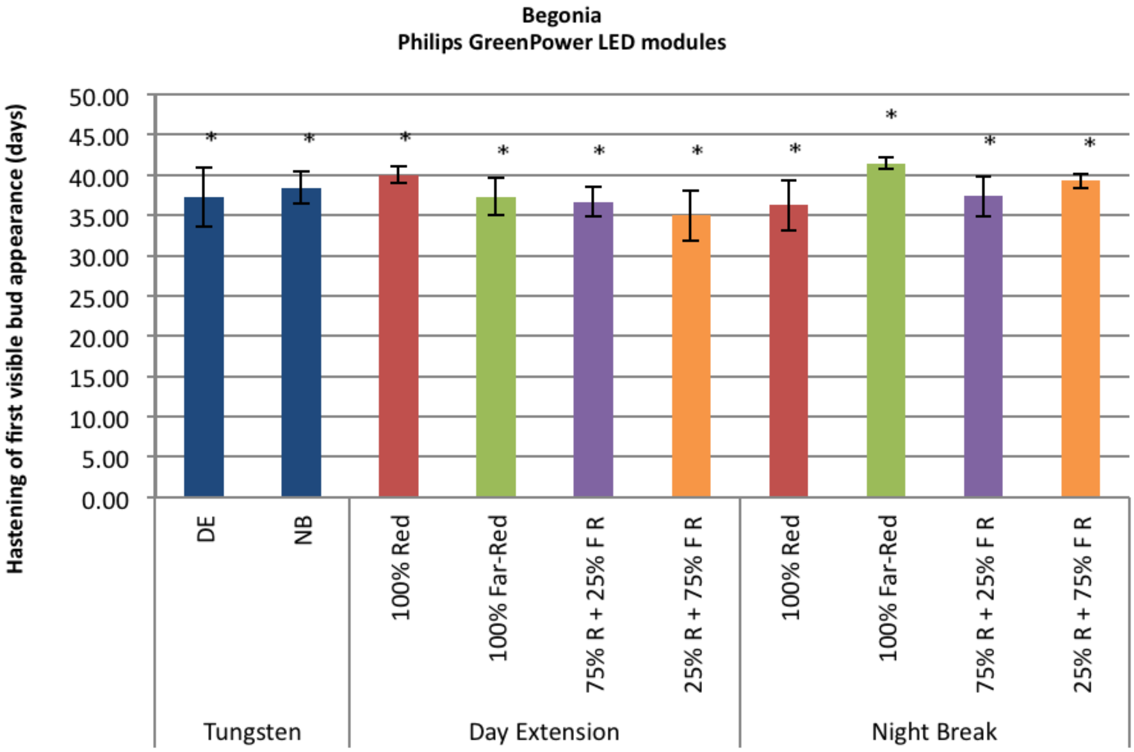


Figure 15. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB, on the hastening of first visible bud appearance relative to the 100% B only LED treatment, which has been set to 0. Error bars represent SE, LSD = 6.40 and * denotes a significant effect of light treatment on plant response.

Philips GreenPower LED flowering lamps

Tuber development and plant size

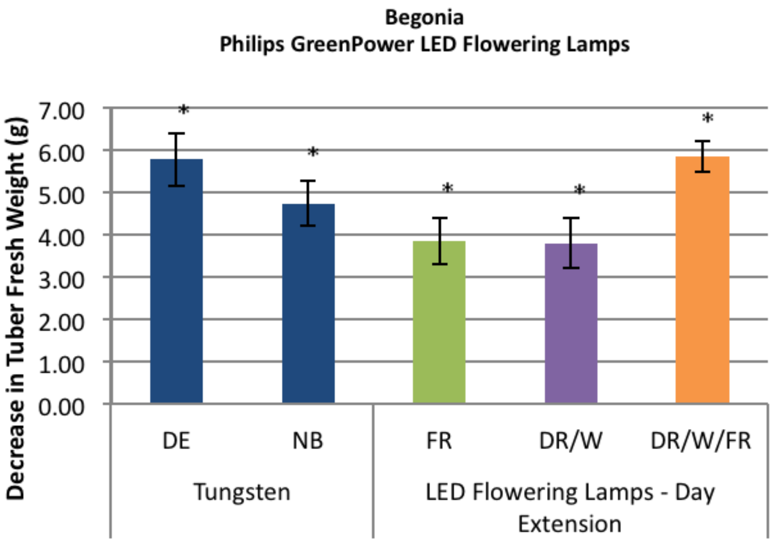


Figure 16. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on decreasing tuber fresh weight (g) relative to the 100% B LED treatment, which has been set to 0. Error bars represent SE, LSD (T) = 2.17/ LSD (LED Flowering Lamps) = 1.82 and * denotes a significant effect of light treatment on plant response.

All the LED flowering lamps tested, and the T LD treatments, significantly ($p<0.05$) decreased tuber fresh weight relative to the 100% B LED treatment, which developed tubers with an average fresh weight of 9.01g (figure 16). DR/W/FR LED flowering lamps and T DE had a comparable impact on tuber fresh weight, leading to a reduction of 5.85 and 5.77g, respectively. DR/W/FR also proved more effective than DR/W and FR LED flowering lamps, which both reduced tuber fresh weight by 3.8g. T NB appears to be slightly (not statistically) less effective than T DE, reducing tuber fresh weight by 4.74g.

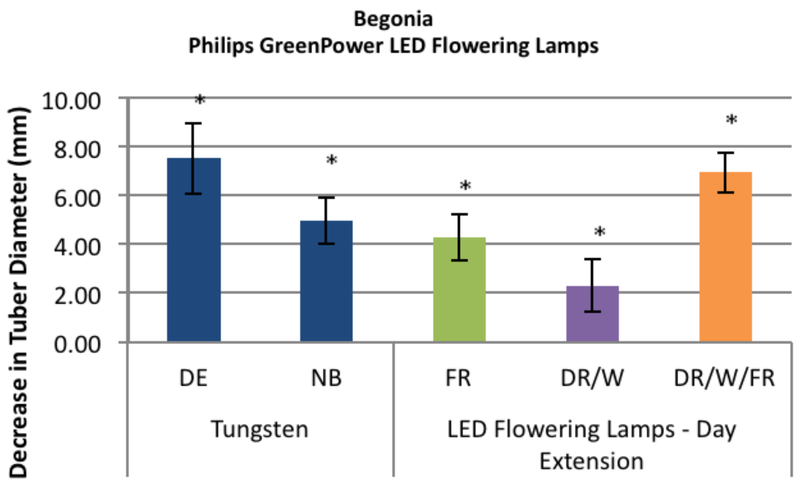


Figure 17. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on decreasing tuber diameter (mm) relative to the 100% B LED treatment, which has been set to 0. Error bars represent SE, LSD (T) = 4.12/ LSD (LED Flowering Lamps) = 3.45 and * denotes a significant effect of light treatment on plant response.

All LD treatments compared in figure 17, with the exception of the DR/W LED flowering lamp, had a significant impact on decreasing tuber diameter. Similarly to tuber fresh weight, DR/W/FR LED flowering lamps and T DE had comparable effects, decreasing tuber diameter by 7.52 and 6.95mm respectively. DR/W/FR LED flowering lamps were statistically more effective at decreasing tuber diameter than DR/W and FR LED flowering lamps.

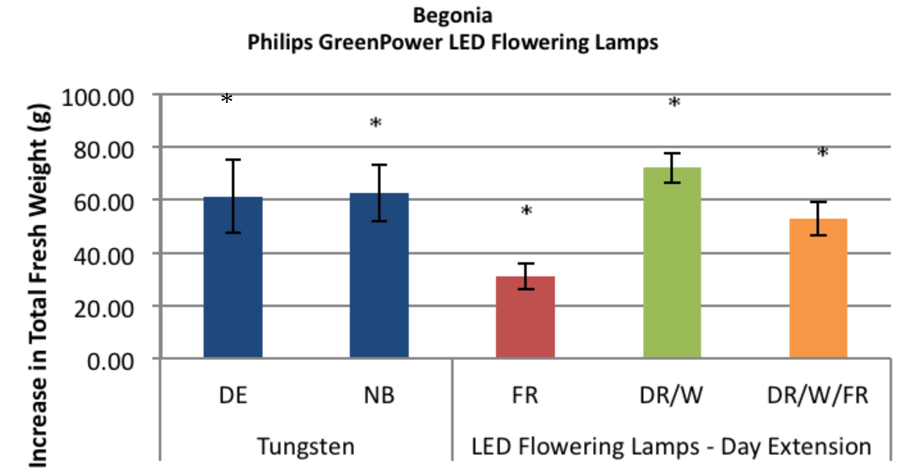


Figure 18. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on increasing total fresh weight (g) relative to the 100% B LED treatment, which has been set to 0. Error bars represent SE, LSD (T) = 27.54/ LSD (LED Flowering Lamps) = 23.05 and * denotes a significant effect of light treatment on plant response.

All LD treatments significantly increased plant total fresh weight by 27-68g (figure 18). The FR LED flowering lamps are significantly less effective at increasing fresh weight when compared to the T LD treatments and the other two LED flowering lamps tested. DR/W DE has the greatest impact, increasing total fresh weight by 68.3g relative to 100% B LED treatment, and is therefore significantly more effective than the other two flowering lamp types and comparable with both T DE and T NB.

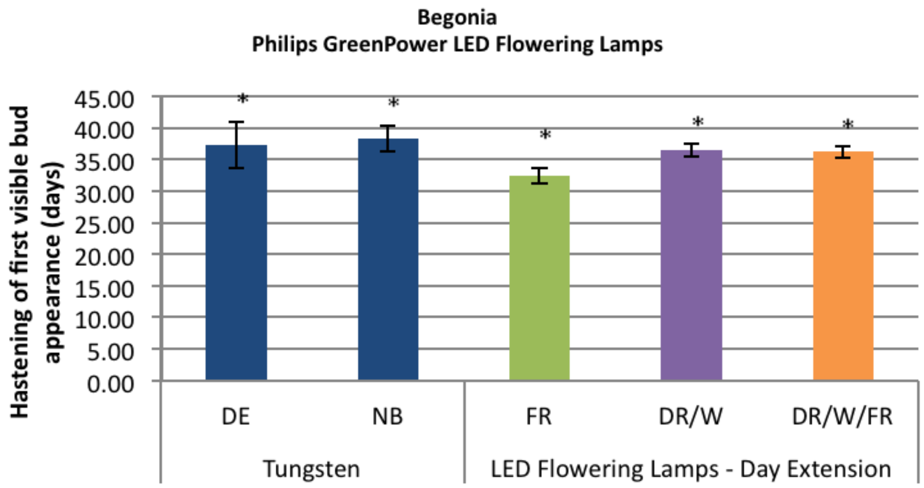


Figure 19. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on hastening the appearance of visible buds (days) relative to the 100% B LED treatment, which has been set to 0. Error bars represent SE, LSD (T) = 7.25/ LSD (LED Flowering Lamps) = 5.62 and * denotes a significant effect of light treatment on plant response.

All LD treatments had a significant impact on the appearance of buds relative to the 100% B LED treatment (figure 19). The LD treatments hastened the appearance of visible buds by 32-38 days. There is no significant difference between the three LED flowering lamp treatments and T DE however, DR/W/FR and DR/W flowering lamps are statistically more effective than FR DE at hastening the appearance of buds.

Plant Height

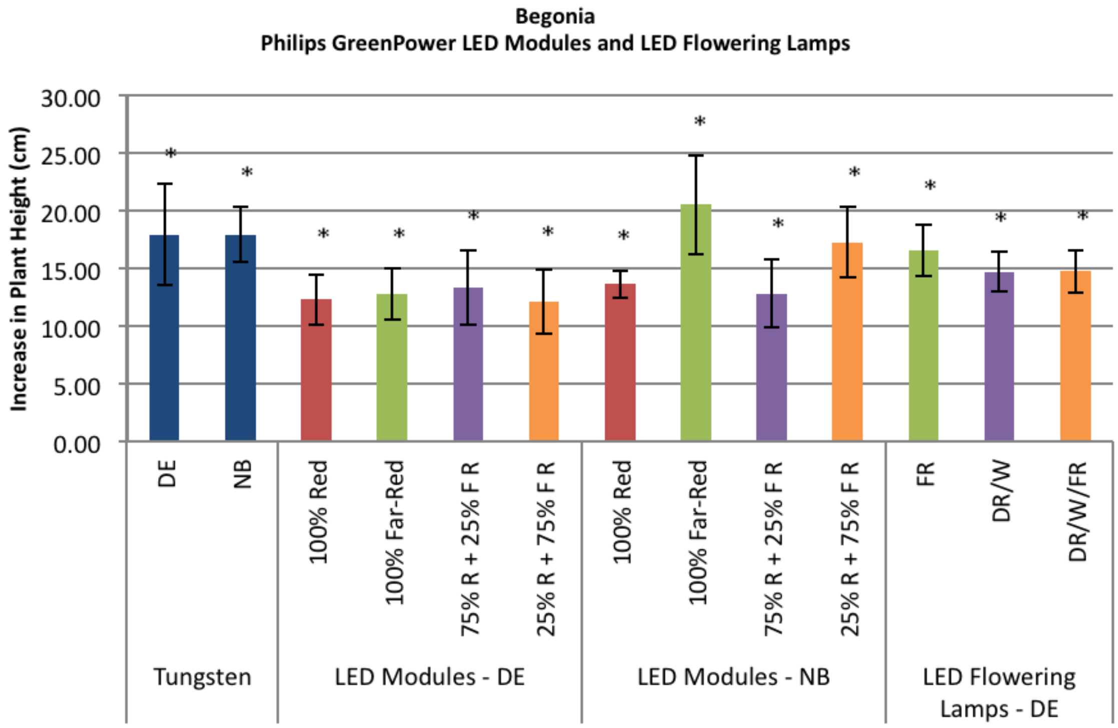


Figure 20. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE) and Philips GreenPower LED modules (DE or NB), on plant height relative to the 100% B LED treatment, which has been set to 0. Error bars represent SE, LSD (LED Modules and T) = 8.48/ LSD (LED Flowering Lamps) = 7.10 and * denotes a significant effect of light treatment on plant response.

On average, plants grown under 100% B DE treatment were 11.5cm tall, all other long day treatments increased plant height between 12.3 and 20.5cm (figure 20). The plant height data was variable between the LD treatments and was not significantly influenced by either the LED module/lamp type or the LD treatment.

Visual summaries of the effect of LED module, LED flowering lamp and T LD treatments relative to the 100% B DE treatment, which had not flowered 129 days into treatment, are presented in figures 21, 22 and 23. All Philips GreenPower LED modules and flowering lamps promoted above ground shoot growth, regardless of the type of LD treatment, whilst plants in the 100% B LED treatment developed tubers at the expense of shoot growth. All LED module and flowering lamp treatments, which developed buds an average of 89-94 and 92-96 days into treatment respectively, hastened the appearance of visible buds relative to the 100% B LED treatment irrespective of lamp/LED type or LD treatment.

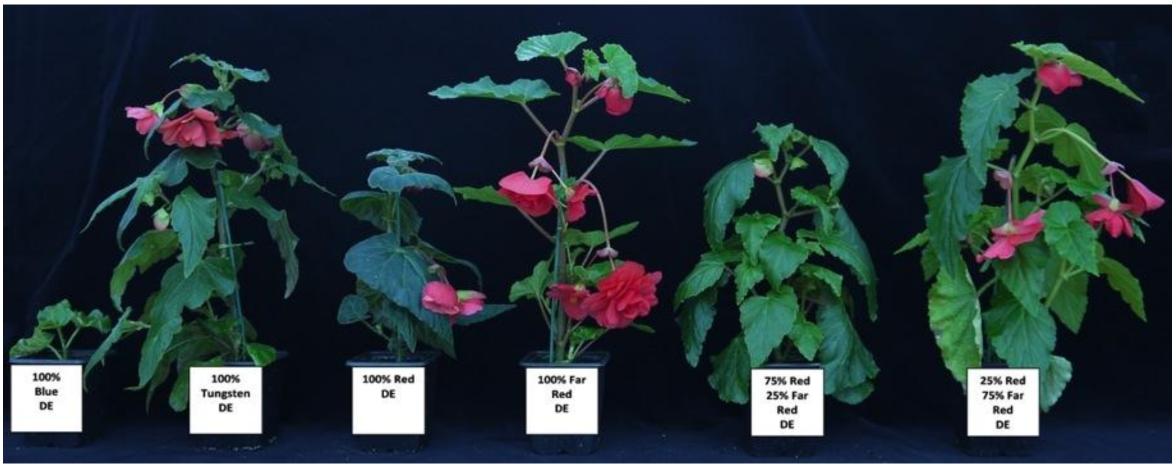


Figure 21. Begonia: The effect of DE lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and 100% B LED module DE treatment.

Figure 22. Begonia: The effect of NB lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and 100% B LED module DE treatment.

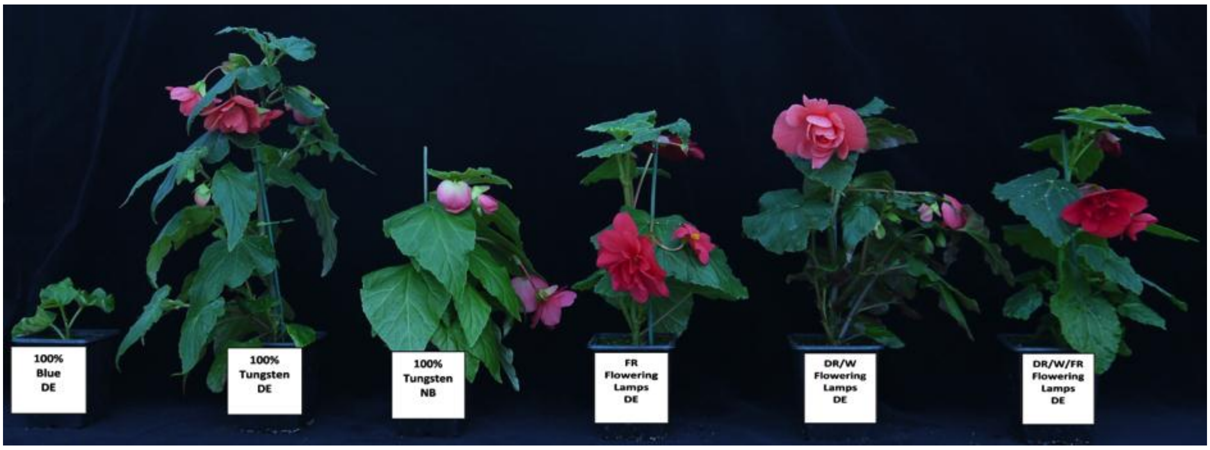


Figure 23. Begonia: The effect of DE lighting with three types of Philips GreenPower LED flowering lamps in comparison to T lamps, both DE and NB, and 100% B LED module DE treatment.

Christmas Cactus Olga

In the first experiment, Christmas cactus was the only SD species tested where CF lamps were less effective than T at controlling flowering. T DE was the most effective treatment for delaying flowering, where T NB, CF NB and CF DE also delayed flowering compared to the SD control treatment but not to the same extent. Therefore, CF would not be an appropriate replacement for T.

Philips GreenPower LED modules

Development of visible buds

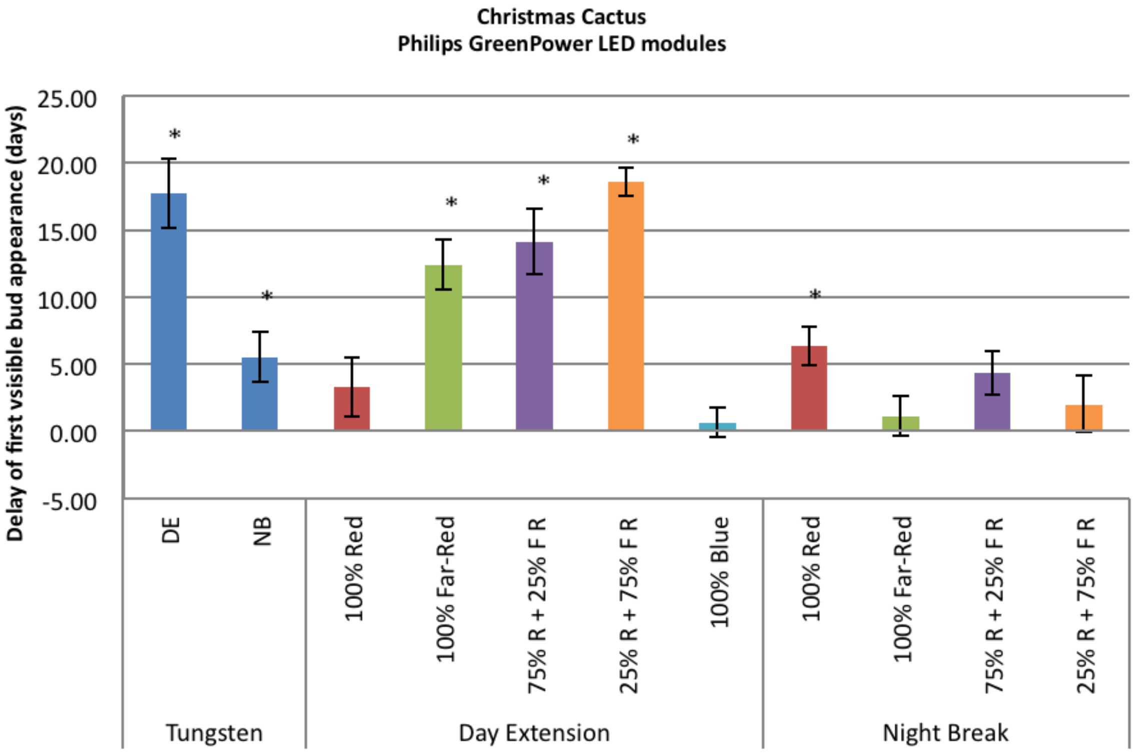


Figure 24. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB treatment, on the delay of first visible bud appearance relative to the short day control, which has been set to 0. Error bars represent SE, LSD = 4.73 and * denotes a significant effect of light treatment on plant response.

T DE and T NB significantly ($p<0.05$) delayed the appearance of visible buds in comparison to the SD control, which developed visible buds after 13 days (figure 24). Again, the T DE treatment proved to be significantly more effective than T NB, delaying flowering by 18 and 6 days respectively.

The different LED modules gave varying levels of flowering control for both DE and NB treatments. The LED module DE treatments 100% FR, 75%R+25%FR and 25%R+75%FR were able to significantly delay the appearance of visible buds relative to the SD control, whereas when delivered as NB treatments, those containing FR light were statistically no different to the SD control. The reverse is observed for the 100% R LED modules; delivered as a DE treatment the appearance of buds is not delayed, conversely as a NB treatment red only is able to significantly delay the development of buds. Although 100% R NB had a greater influence on the delay of bud appearance compared to the FR containing NB treatments, it was significantly ($p<0.05$) less effective than T DE. The 100% B DE treatment tested was statistically no different to the SD control treatment, with plants producing buds 12-13 days into treatment (figure 24).

Of the LED modules and long day treatments tested, a DE with 25%R+75%FR had the greatest impact on the development of buds and is statistically no different to T DE as both treatments resulted in an average delay of 18-19 days.

Development of flowers from first visible bud

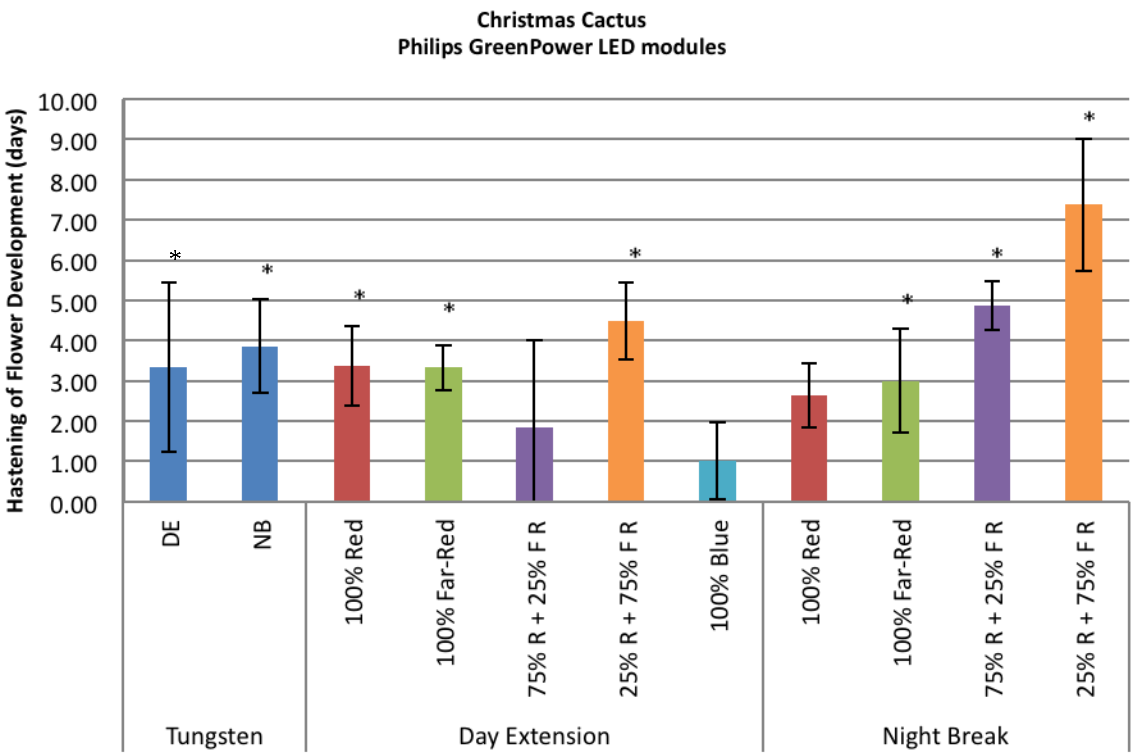


Figure 25. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB, on number of days from bud to flower relative to the short day control, which has been set to 0. Error bars represent SE, LSD = 3.26 and * denotes a significant effect of light treatment on plant response.

Four of the LD treatments tested had a significant ($P<0.05$) influence over the time taken for visible buds to develop into flowers compared with the SD control where buds developed into flowers in an average of 54 days (figure 25). 25%R+75%FR DE, 75%R+25%FR NB and 25%R+75%FR NB all had a significant impact, hastening flower development by 4.5, 4.8

and 7.4 days respectively. Whilst T NB hastened flower development (by an average of 3.8 days) the treatment was significantly less effective at controlling flower development than a NB of 25%R-75%FR.

Philips GreenPower LED Flowering Lamps

Development of visible buds

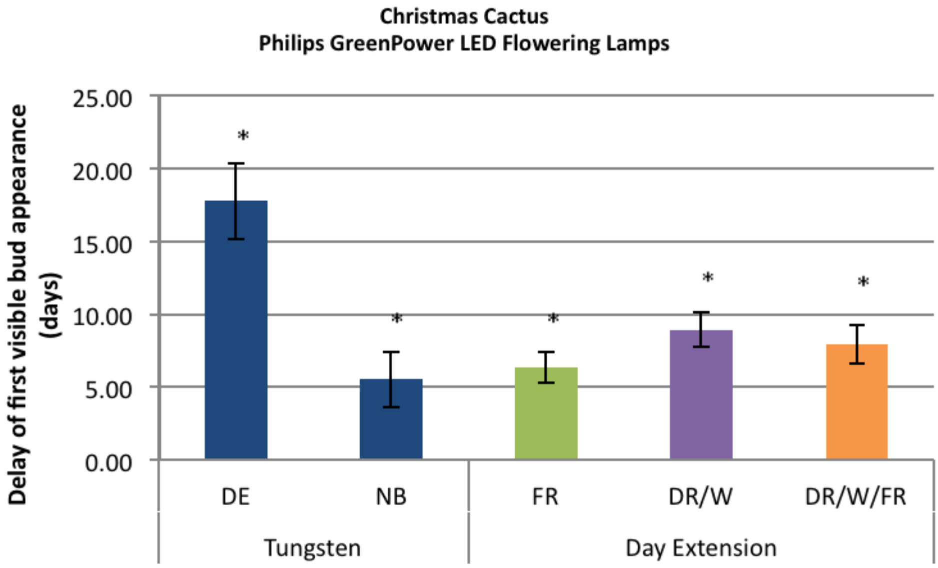


Figure 26. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on delaying bud appearance relative to the short day control, which has been set to 0. Error bars represent SE, LSD (T) = 5.64 / LSD (LED Flowering Lamps) = 4.58 and * denotes a significant effect of light treatment on plant response.

All of the LED flowering lamp DE treatments significantly ($p<0.05$) delayed the appearance of visible buds when compared with the SD control, which developed visible buds after 13 days of treatment (figure 26). Statistically, the flowering lamps and the T NB treatment were no different to one another, all producing visible buds 18-21 days into treatment. The T DE treatment, which produced buds 31 days into treatment, has a significantly larger impact on the delay of bud appearance than T NB and the flowering lamp treatments tested.

Development of flowers from first visible bud

In comparison to the SD control, the flowering lamps resulted in a significant ($p<0.05$) hastening of flower development of 6-8 days. Statistically, neither T DE nor T NB has an impact on the time taken for buds to develop into flowers (figure 27).

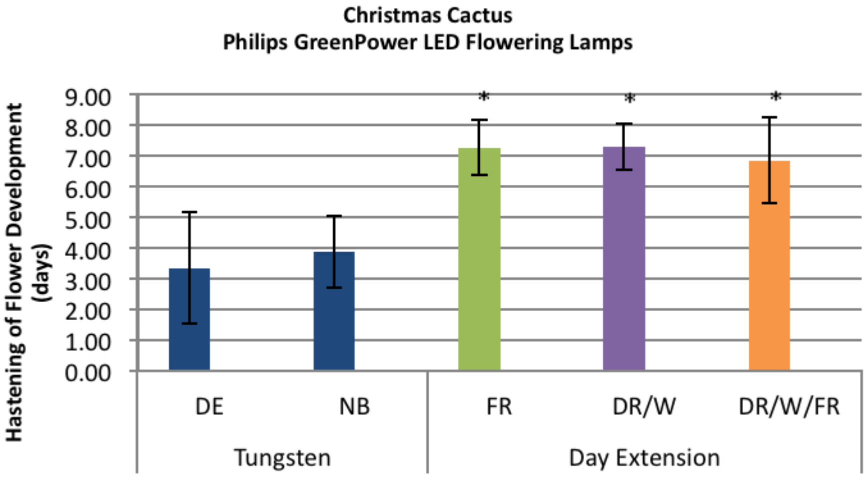


Figure 27. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on number of days from bud to flower relative to the short day control, which has been set to 0. Error bars represent SE, LSD (T) = 4.85 / LSD (LED Flowering Lamps) = 3.94 and * denotes a significant effect of light treatment on plant response.

Plant Height

None of the LD treatments tested had a significant ($p<0.05$) effect on plant height for Christmas cactus (figure 28).

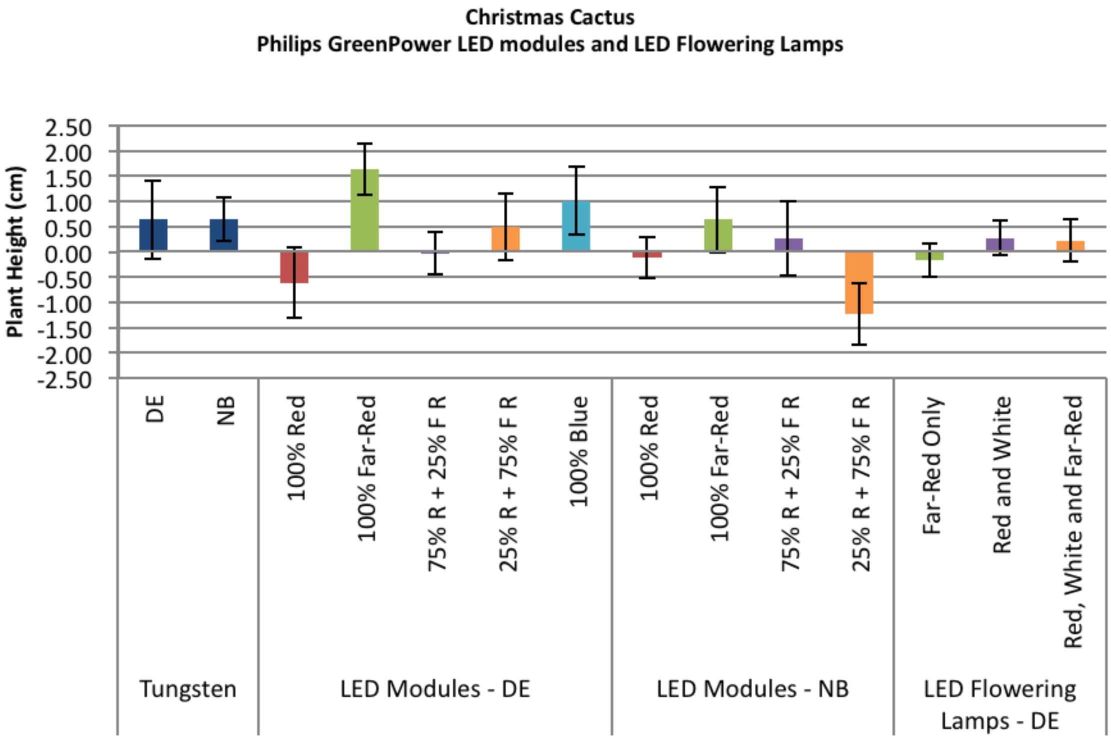


Figure 28. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on plant height relative to the short day control, which has been set to 0. Error bars represent SE, LSD (LED Modules and T) = 1.75/ LSD (LED Flowering Lamps) = 1.45 and * denotes a significant effect of light treatment on plant response.

Visual summaries of the effect of LED module, LED flowering lamp and T LD treatments relative to the SD control, which flowered on average 66 days into treatment, are presented in figures 29, 30 and 31. Comparing LED modules as DE treatments, T and 25%R+75%FR were the most effective at delaying flowering of Christmas cactus, flowering 81 and 79 days into treatment, respectively. In contrast, R and B LED modules had no influence on flowering, developing first open flowers on average 66 days into treatment (figure 29). Of the NB treatments, 25%R+75%FR hastened flowering by an average of 5 days relative to the SD control, whereas, 75%R+25%FR and 100% FR flowered 65-66 days into treatment, comparable to the SD treatment (figure 30). T NB and 100% R NB resulted in a small delay in flowering, developing open flowers 68-70 days into treatment. The delay in flowering caused by the DR/W flowering lamps, relative to the SD control, is comparable to the T NB treatment, both developing open flowers 68 days into treatment (figure 31). Whereas FR and DR/W/FR flowering lamp DE treatments flowered 65 and 67 days into treatment, respectively. N.B Plants used in these trials were obtained partly grown and had already received T DE extension lighting on the commercial nursery site before starting the experimental treatments; hence the data here may not show the full extent of the differences between lamp types and LD treatment.

Figure 29. Christmas cactus: The effect of DE lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

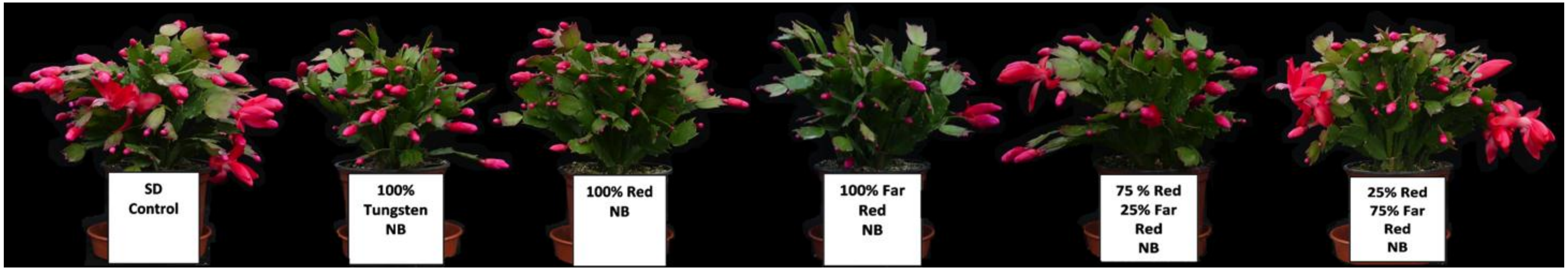


Figure 30. Christmas cactus: The effect of NB lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

Figure 31. Christmas cactus: The effect of DE lighting with different types of Philips GreenPower LED flowering lamps in comparison to T lamps (DE and NB) and a SD control.

Chrysanthemum Tampico White

CF lighting was able to control flowering effectively for chrysanthemum; both CF and T LD treatments remained vegetative until they had produced around 17-20 leaves on the side shoot and then budded autonomously. Therefore, CF lamps appear to be a suitable replacement for T lighting for chrysanthemum.

Philips GreenPower LED Modules

Development of visible buds

By the end of the experiment (91 days into treatment) only three of the LD treatments contained plants which had produced visible buds. For those treatments where buds have not been produced, the delay is shown graphically as 62 days relative to the SD control, which is indicated by a V over the respective column in figure 32. This is an estimate and the actual delay for these treatments would be greater than shown here. All T LD and LED module LD treatments delayed flowering of chrysanthemum relative to the SD control, which produced visible buds on average 29 days into treatment (figure 32).

Visible buds were produced by plants in the 100% B LED module treatment, on average 30 days into treatment, with no significant difference between this and the SD treatment (figure 32). The 100% FR LED module treatment delayed the appearance of visible buds by 39 days as a NB treatment, and by 52 days as a DE treatment.

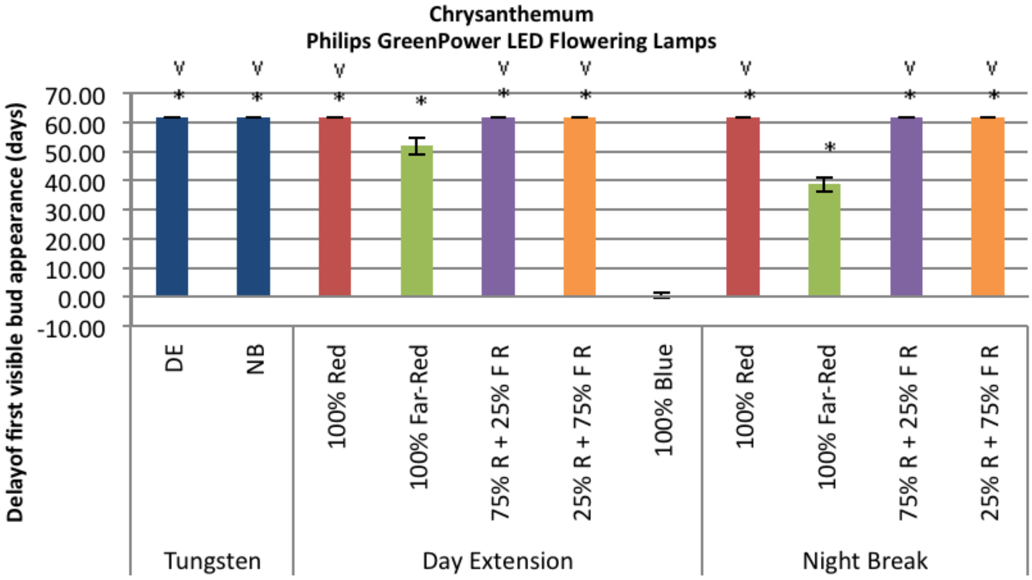


Figure 32. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB, on number of days to first visible bud relative to the short day control, which has been set to 0. Error bars represent SE, LSD = 2.88, * denotes a significant effect of light treatment on plant response and V denotes plants that remained vegetative after 91 days in treatment.

As very few of the LD treated plants produced visible buds and open flowers before the end of the experiment, the time for flowers to develop was not estimated. Of the treatments that did develop visible buds and subsequently open flower (SD control, 100% B DE and 100% FR NB), development to flower 'stage 6' (see appendix I) took an average of 20 days for each of the treatments.

The delay of visible bud appearance data was reinforced by leaf counts taken at the end of the experiment (91 days into treatment). It is clear that all LD treatments, with the exception of 100% B DE, delayed flowering as all plants had a significant (P<0.05) increase in leaf number on the most developed side shoot compared with plants in SD treatments (figure 33). There were 8-12 additional leaves produced on the side shoots of those plants which did not produce visible buds by the end of the experiment. There was no significant difference in leaf number between 100% B DE LED treatment and the SD control, which both had an average of 12 leaves on each side shoot at the time of first visible bud appearance. The 100% FR NB had only 6 additional leaves compared to the SD control and was the least effective LD treatment, delaying visible bud appearance by only 39 days.

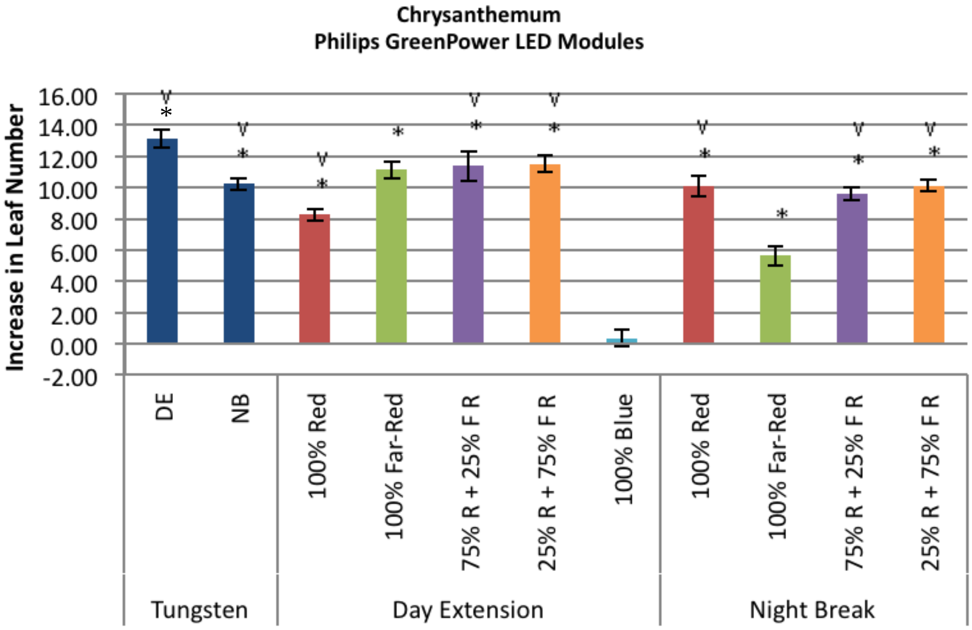


Figure 33. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB, on the leaf count of the most developed side shoot of each plant, relative to the short day control, which has been set to 0. Error bars represent SE, LSD = 1.56, * denotes a significant effect of light treatment on plant response and V denotes plants that remained vegetative after 91 days in treatment.

Philips GreenPower LED Flowering Lamps

Development of visible buds

All of the LED flowering lamp DE treatments significantly delayed the appearance of visible buds when compared with the SD control (figure 34). Similarly to the LED modules in the photoperiod cabinet experiments, visible buds were not produced by all of the LED flowering lamps tested. Therefore, the delay for those that had not flowered by the end of the experiment is shown graphically as 62 days, it should be noted that the actual delay would be greater than this.

The FR LED flowering lamp was the least effective at delaying flowering, delaying bud appearance by 36 days relative to the SD control, which produced buds 30 days into treatment. As with the T NB and T DE treatments, neither the DR/W or DR/W/FR flowering lamps had produced visible buds by the end of the experiment, proving effective at delaying flowering in chrysanthemum (figure 34).

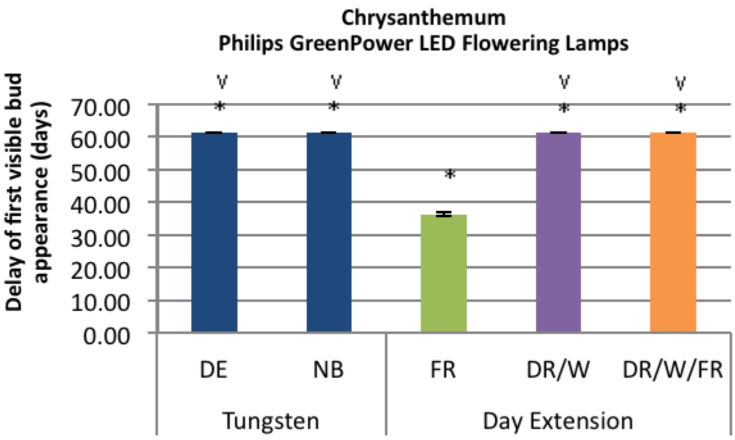


Figure 34. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on delaying bud appearance relative to the short day control, which has been set to 0. Error bars represent SE, LSD (T) = 1.75/ LSD (LED Flowering Lamps) = 1.42, * denotes a significant effect of light treatment on plant response and V denotes plants that remained vegetative after 91 days in treatment.

The FR LED flowering lamp was the only LD treatment to produce visible buds, which subsequently developed to flower ‘stage 6’ in an average of 18 days, comparable to flower development (20 days) under SD conditions.

Leaf counts taken at the end of the experiment also indicate that the LD treatments tested delayed flowering. Plants grown under DR/W and DR/W/FR had a significant ($P<0.05$) increase in leaf number on the most developed side shoot compared with plants in SD treatments (figure 35), producing 10-14 additional leaves. Those under FR LED flowering lamp treatment had only 6 additional leaves compared to the SD control and was the least effective LD treatment, delaying visible bud appearance by only 36 days.

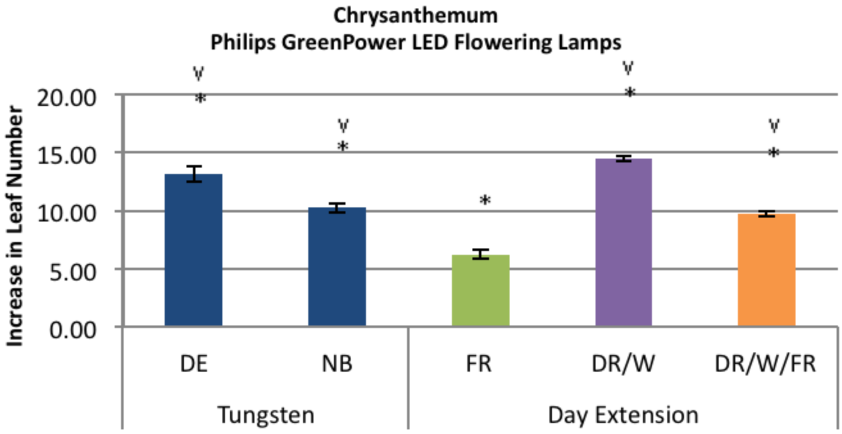


Figure 35. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on the leaf count of the most developed side shoot of each plant, relative to the short day control, which has been set to 0. Error bars represent SE, LSD (T) = 1.43/ LSD (LED Flowering Lamps) = 1.16, * denotes a significant effect of light treatment on plant response and V denotes plants that remained vegetative after 91 days in treatment.

Plant Height

The effect of LED type on plant height was assessed relative to the SD control (figure 36). With the exception of 100% B DE, all LD treatments produced plants that were significantly taller than those under SDs, which were on average 26cm. In particular, the LED modules and flowering lamps that contain FR light produced the tallest plants, 21-35cm taller than the SD control. T DE and T NB produced plants that were on average 27-28cm taller than the SD control.

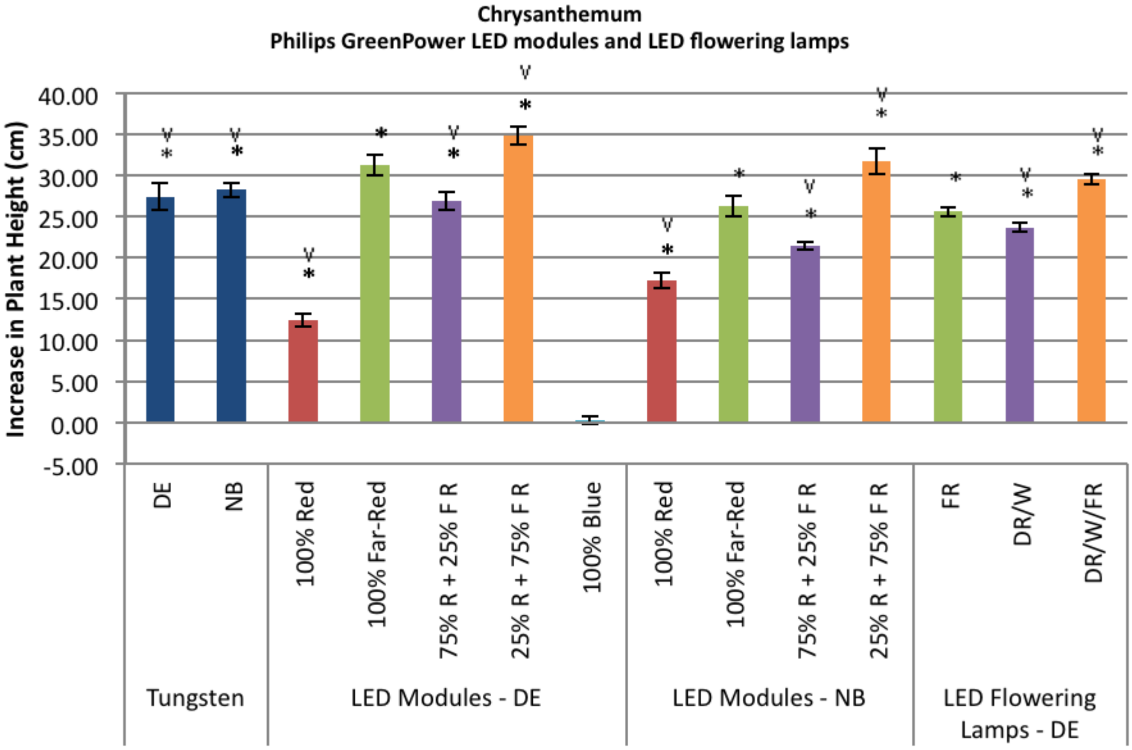


Figure 36. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE) and Philips GreenPower LED modules (DE or NB), on plant height relative to the short day control, which has been set to 0. Error bars represent SE, LSD (LED Modules and T) = 2.88/ LSD (LED Flowering Lamps) = 2.34, * denotes a significant effect of light treatment on plant response and V denotes plants that remained vegetative after 91 days in treatment.

Visual summaries of the effect of LED module, LED flowering lamp and T LD treatments relative to the SD control, which flowered on average 50 days into treatment, are presented in figures 37, 38 and 39. Figure 37 shows a comparison between LED module DE treatments and T DE; the 100% B LED treatment was ineffective at delaying flowering; the 100% FR LED treatment was effective at delaying flowering, flowering 90 days into treatment; and similarly to T DE the remaining LED module treatments were all effective at delaying flowering as none of these treatments had developed visible buds 91 days into treatment. Comparing the LED modules as NB treatments, plants under 100% FR LED modules flowered 85 days into treatment, delaying flowering by 35 days relative to the SD control (figure 38). The T NB and the remaining LED module treatments were more effective than the 100% FR treatment at delaying flowering as none of these treatments had produced visible buds by the end of the experiment. All flowering lamp DE treatments caused a delay in flowering relative to the SD control (figure 39). Plants grown under FR lamps flowered 84 days into treatment whereas plants grown under DR/W and DR/W/FR lamps had not produced visible buds by the end of the experiment.

Figure 37. Chrysanthemum: The effect of DE lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

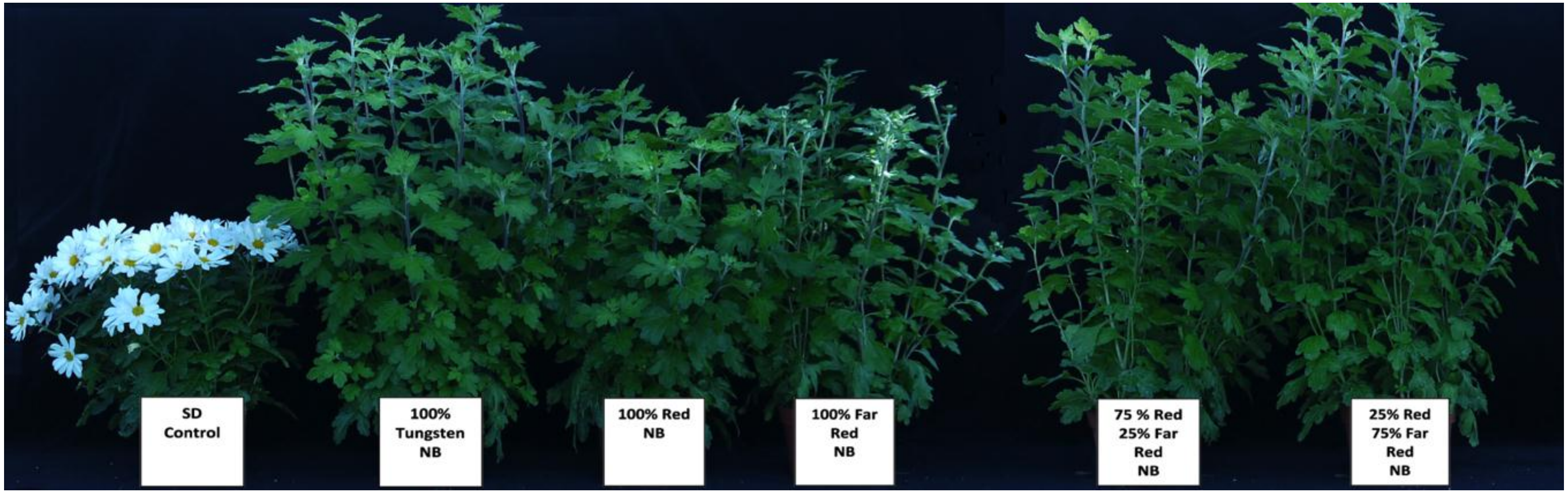


Figure 38. Chrysanthemum: The effect of NB lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

Figure 39. Chrysanthemum: The effect of DE lighting with different types of Philips GreenPower LED flowering lamps in comparison to T lamps (DE and NB) and a SD control.

Lisianthus Florida Silver

The light spectrum from CF lamps did not match that from T lamps well enough to control flowering effectively for lisianthus. Plants grown with CF DE lighting treatment flowered at a similar time to the SD treatment and although the CF NB lighting treatment was more effective it was unable to hasten flowering to the same degree as T NB.

Philips GreenPower LED Modules

Development of visible buds

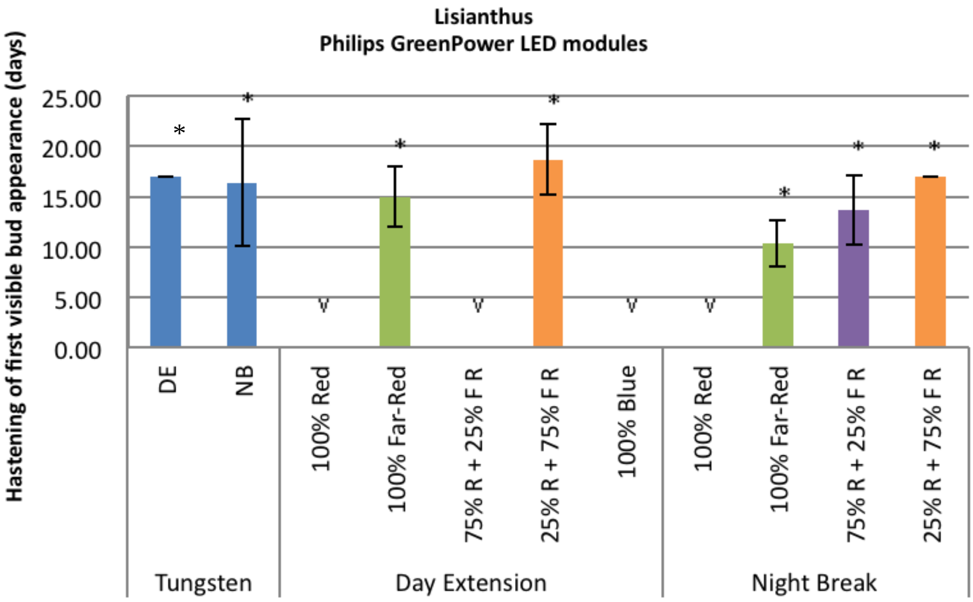


Figure 40. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB, on hastening bud appearance relative to the short day control, which has been set to 0. Error bars represent SE, LSD = 4.03 and * denotes a significant effect of light treatment on plant response and V denotes plants that remained vegetative after 156 days in treatment.

Lisianthus Florida silver grown in SDs had not produced visible buds by the end of the experiment, 156 days into treatment. Limited data are available for the photoperiod cabinet experiments as 100% R DE, 75% R+25% FR DE, 100% B DE and 100% R NB had also not produced visible buds within the project timeframe; for these treatments the appearance of visible buds has been set at 156 days and shown in figure 40 as having hastened visible bud appearance by 0 days relative to the SD control. The actual reduction in time taken to produce buds would be larger than represented in figure 40.

Therefore, the time for lisianthus to develop visible buds was significantly ($p<0.05$) reduced, relative to the SD control, when plants were given LD treatment with T lamps, T DE hastened bud appearance on average by 17 days and T NB hastened bud appearance on average by 16 days. The LED module treatments which had developed buds by the end of the experiment were all able to significantly reduce the time taken for buds to appear; the LED module NB treatments containing FR light hastened bud appearance by 10-17 days, whereas, the LED module DE treatments that hastened bud appearance did so by 15-19 days. The most effective treatments for hastening the appearance of buds relative to the SD control were 25%R+75%FR delivered as both DE and NB.

Philips GreenPower Flowering Lamps

Development of visible buds

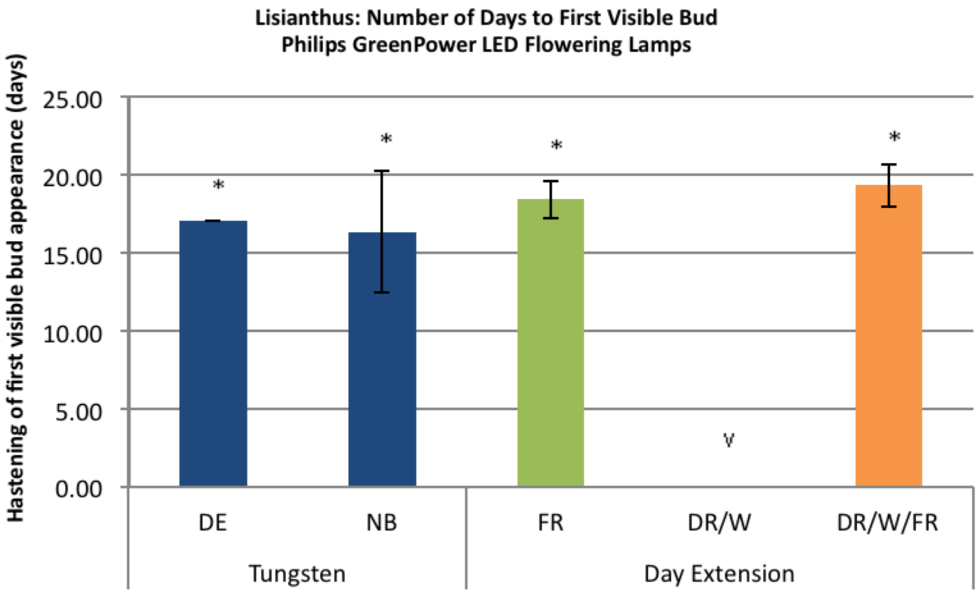


Figure 41. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on the hastening of first visible bud appearance relative to the short day control, which has been set to 0. Error bars represent SE, LSD (T) = 5.16/ LSD (LED Flowering Lamps) = 4.00 and * denotes a significant effect of light treatment on plant response and V denotes plants that remained vegetative after 156 days in treatment.

Lisianthus plants grown in SDs and those grown under DR/W flowering lamps had not produced visible buds by the end of the experiment. Therefore, visible bud appearance has been set at 156 days and shown in figure 41 as having hastened bud appearance by 0 days relative to the SD control. The FR and DR/W/FR flowering lamps significantly hastened the appearance of visible buds by 18 and 19 days, respectively. Both of these treatments were statistically equivalent to T DE and NB, which produced buds 16-17 days earlier than the SD control (figure 41).

Plant Height

On average lisianthus grown in SD were 20cm tall, the impact of the LD treatments on plant height is represented in figure 42. T DE had a significant influence, increasing plant height by 3cm, whereas, T NB, 75%R+25%FR DE, 100% B DE and 100% R NB did not cause a significant difference in plant height. The DE treatments containing large proportions of FR light had the greatest impact, with plants 9-10cm taller than the SD control (figure 42).

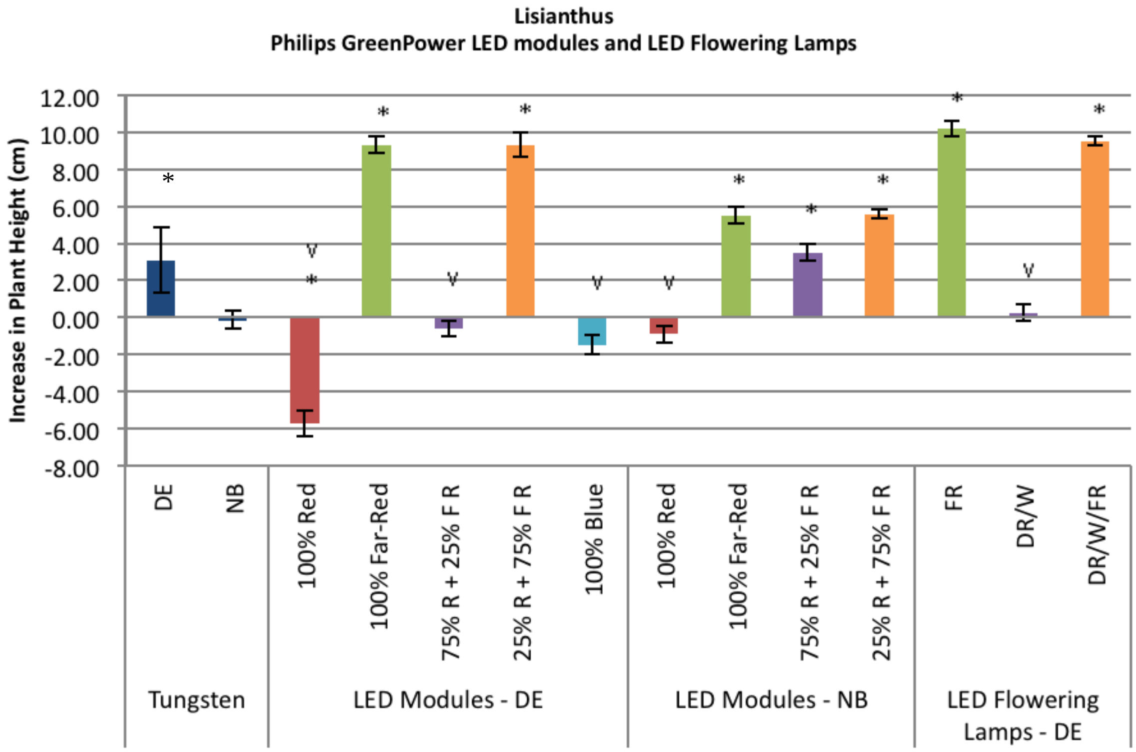


Figure 42. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on plant height relative to the short day control, which has been set to 0. Error bars represent SE, LSD (LED Modules and T) = 1.75/ LSD (LED Flowering Lamps) and * denotes a significant effect of light treatment on plant response and V denotes plants that remained vegetative after 156 days in treatment.

Visual summaries of the effect of LED module, LED flowering lamp and T LD treatments relative to the SD control, which had not produced visible buds 156 days into treatment, are presented in figures 43, 44 and 45. In figure 43 LED module DE treatments and T DE are compared; as for the SD control the 100% R, 75%R+25%FR and 100% B LED treatments had not produced buds by the end of the experiment. T, 100% FR and 25%R+75%FR DE treatments are all comparable, having produced visible buds 139, 141 and 137 days into treatment, respectively. At the end of the experiment, flower development appeared to be most advanced for those plants under 25%R+75%FR treatment (figure 43). Figure 44 compares LED module NB treatments and T NB; T, 100% FR, 75%R+25%FR and 25%R+75%FR are all comparable, having produced visible buds 139-145 days into treatment. As with the DE treatments, 25%R+75%FR NB was the most effective treatment, hastening bud appearance by an average of 139 days. The FR and DR/W/FR flowering lamps delivered as DE treatments reduced the time taken for plants to bud relative to the

SD control (figure 45). Plants grown under FR and DR/W/FR lamps produced buds 137 days into treatment and were therefore, as effective as T DE at hastening development in lisianthus Florida silver compared with the SD control. Plants grown under DR/W lamps had not produced visible buds 156 days into treatment.

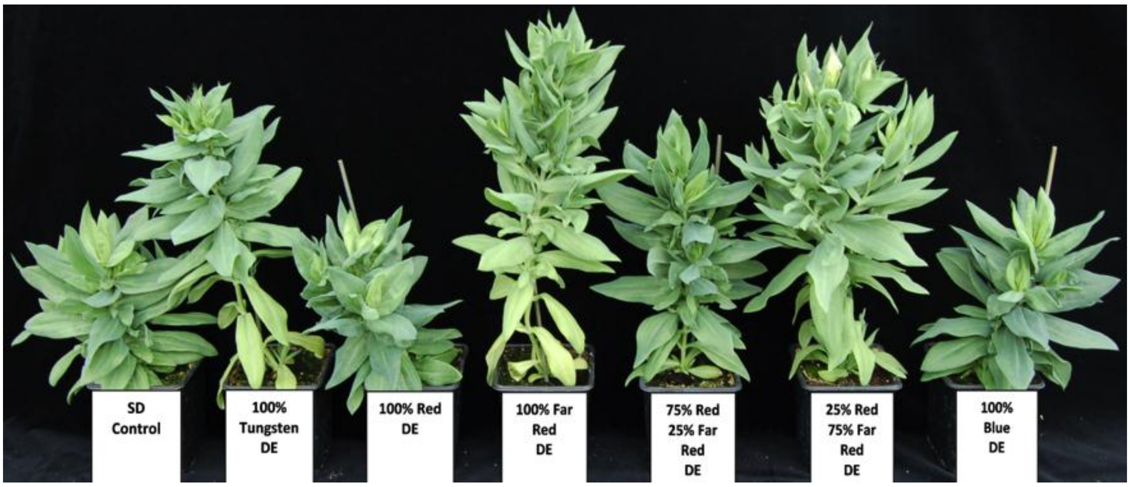


Figure 43. Lisianthus: The effect of DE lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

Figure 44. Lisianthus: The effect of NB lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

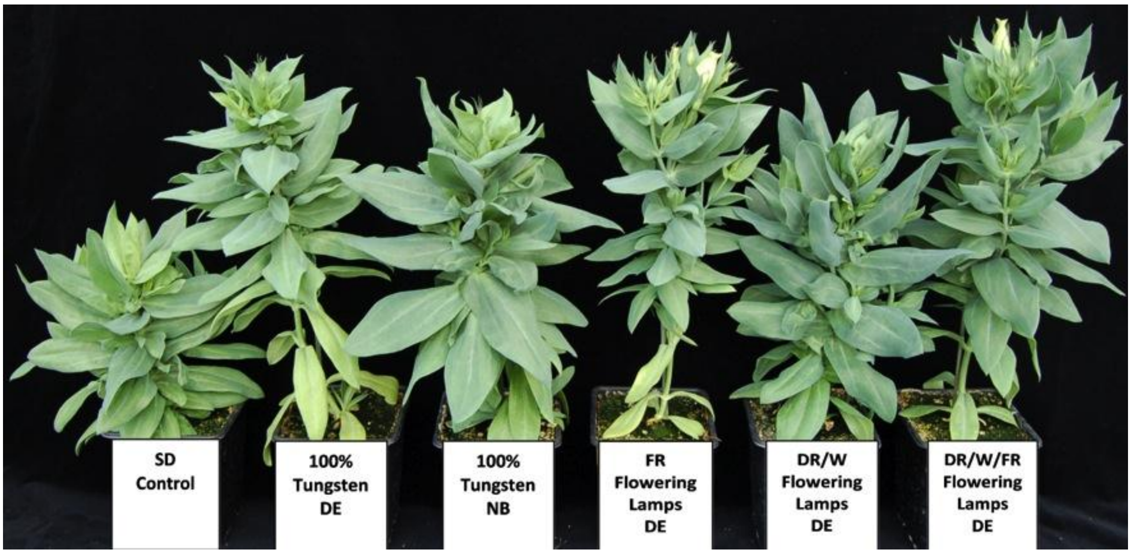


Figure 45. Lisianthus: The effect of DE lighting with different types of Philips GreenPower LED flowering lamps in comparison to T lamps (DE and NB) and a SD control.

Pansy Majestic Giant Purple

Compact fluorescent lighting was less effective than T lamps for pansy (Majestic giant purple), DE lighting with CF lamps proved ineffective (plants flowered at a similar time to the SD treatment). NB lighting with CF lamps was more effective, although it did not tend to hasten flowering as much as T NB.

Philips GreenPower LED Modules

Development of visible buds

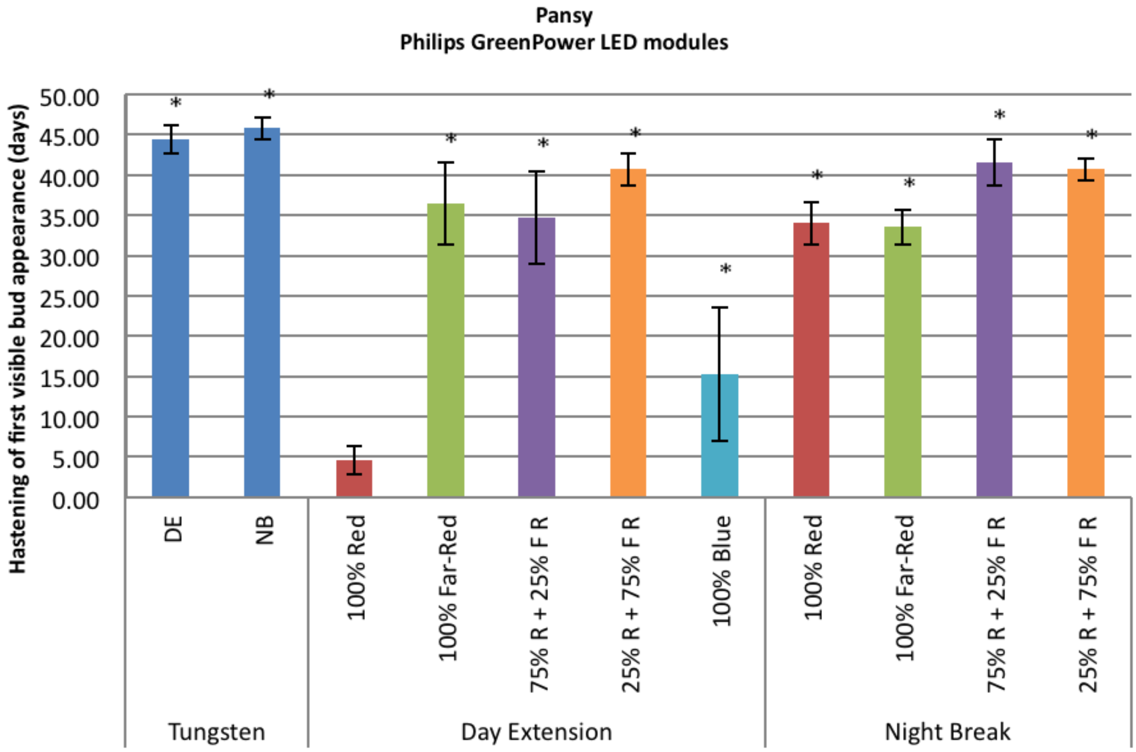


Figure 46. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB, on the hastening of first visible bud appearance relative to the short day control, which has been set to 0. Error bars represent SE, LSD = 10.56 and * denotes a significant effect of light treatment on plant response.

Relative to the SD control, which produced visible buds 81 days into treatment, visible buds appeared significantly earlier ($p<0.05$) when plants were exposed to T as DE or NB (figure 46). The LED module treatments containing far-red light (both DE and NB) were effective at hastening the appearance of buds, visible buds developed 33-42 days earlier in these treatments than the SD control. In comparison with T DE and NB treatments, the most effective LED module combinations were 25%R+75%FR DE, 75%R+25%FR NB and 25%R+75%FR NB, which hasten the appearance of buds by 40-42 days.

Statistically, the 100% R LED module had no impact as a DE treatment relative to the SD control, producing buds on average 77 days into treatment. However, the same LED type was able to significantly hasten bud appearance (by 34 days) when given as a NB treatment.

The 100% B LED modules tested as DE treatment significantly hastened the appearance of buds although, by an average of only 10 days. The error bar in figure 46 indicates that the data obtained was variable for 100% B DE and with the exception of 100% R DE, was the least effective LED type for hastening bud appearance.

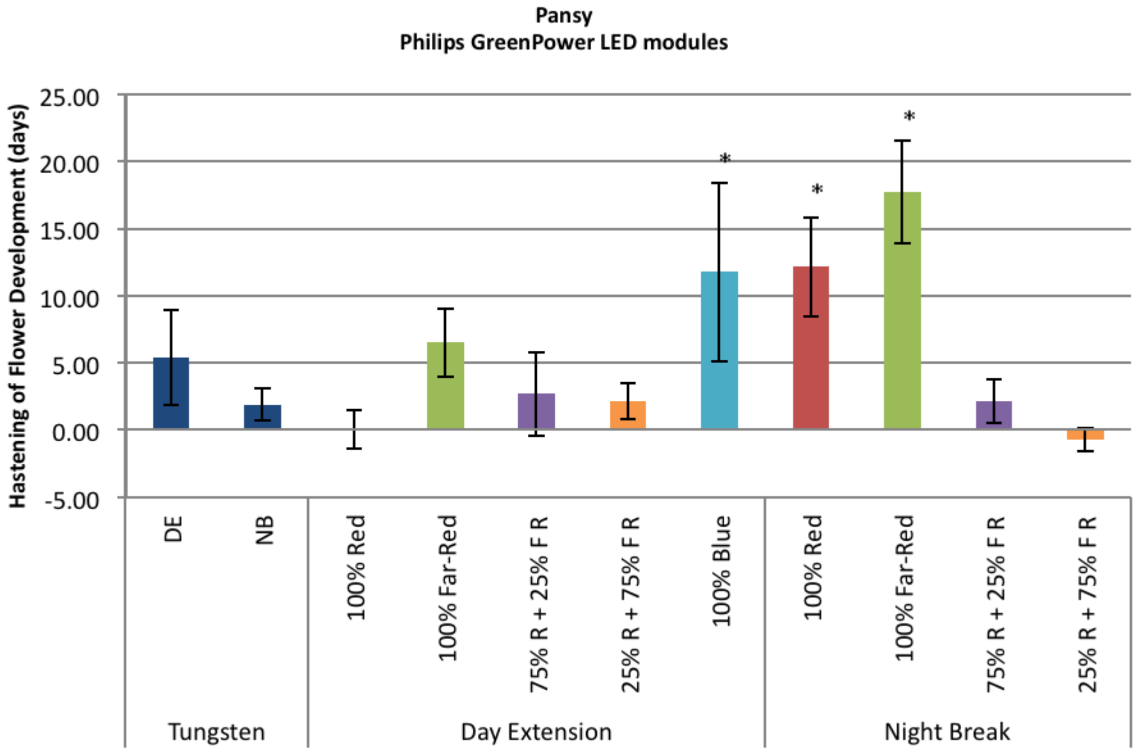


Figure 47. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB treatment, on number of days from bud to flower relative to the short day control, which has been set to 0. Negative numbers indicate where the lighting treatments delayed flower development. Error bars represent SE, LSD = 8.55 and * denotes a significant effect of light treatment on plant response.

Buds developed into flowers after 18-21 days when plants were grown in SDs; comparing the LD treatments presented in figure 47, 100% B DE, 100% R NB and 100% FR NB were the only treatments to significantly reduce this flower development time (by 12-18 days). The remaining LD treatments (including T DE and NB) had no significant influence over flower development time.

Philips GreenPower LED Flowering Lamps

Development of visible buds

Plants grown under T DE and T NB developed visible buds 37 and 35 days into treatment, respectively, compared with 81 days for SD plants. FR and DR/W/FR LED flowering lamps significantly hastened the appearance of visible buds by 45-48 days (figure 48). In contrast, the DR/W LED flowering lamp had no significant influence over the time taken for visible buds to appear.

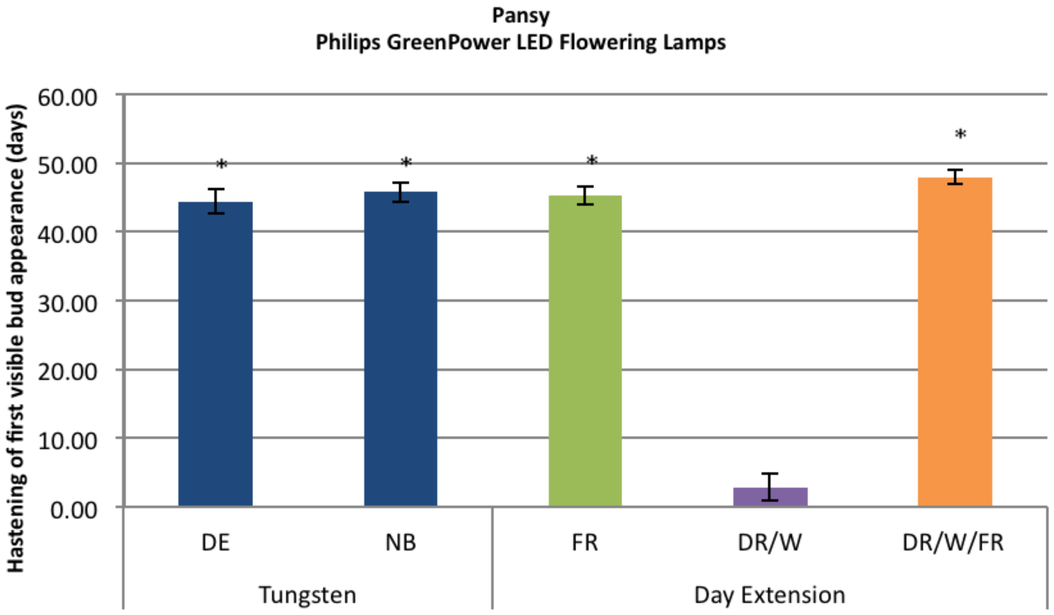


Figure 48. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on the hastening of first visible bud appearance relative to the short day control, which has been set to 0. Error bars represent SE, LSD (T) = 11.06 / LSD (LED Flowering Lamps) = 8.57 and * denotes a significant effect of light treatment on plant response.

Development of flowers from first visible bud

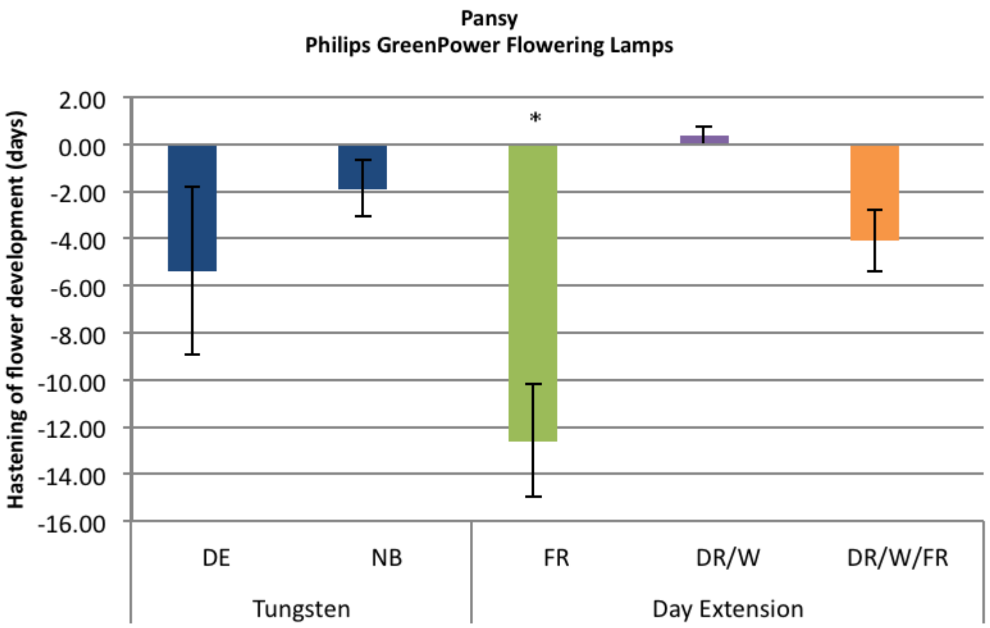


Figure 49. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on the hastening of flower development relative to the short day control, which has been set to 0. Error bars represent SE, LSD (T) = 10.31 / LSD (LED Flowering Lamps) = 7.99 and * denotes a significant effect of light treatment on plant response.

Comparing the LED flowering lamps with T DE and T NB; the FR LED flowering lamp is the only treatment to have a significant impact on flower development relative to the SD control (figure 49). Buds developed into flowers within 18-21 days on plants grown under SD conditions and the FR flowering lamp caused a significant delay of 13 days relative to this. However, the remaining LD treatments (including T DE and NB) had no significant influence on flower development time.

Plant Height

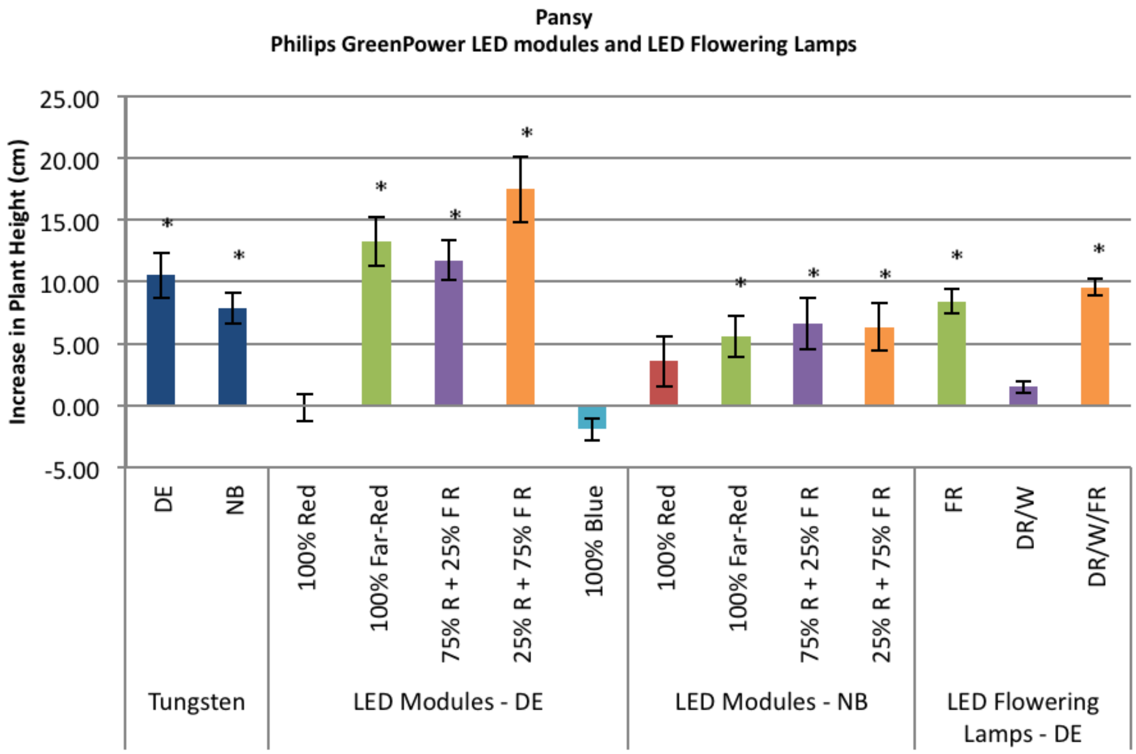


Figure 50. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on plant height relative to the short day control, which has been set to 0. Error bars represent SE, LSD (LED Modules and T) = 4.69 / LSD (LED Flowering Lamps) = 3.63 and * denotes a significant effect of light treatment on plant response.

The effect of the various LD treatments on plant height was assessed relative to the SD control (figure 50). Plants from the SD control were on average 15cm tall; six of the nine LED module treatments and two of the three LED flowering lamp treatments led to a significant increase in the plant height compared with the SD control. 100% B DE, 100% R DE and 100% R NB LED modules and the DR/W LED flowering lamp had no significant impact on the plant height of pansy. The treatments that had the most significant ($p<0.05$) impact on plant height were DE treatments containing FR. 25%R + 75%FR DE had a significantly greater influence than the other LED types, increasing plant height by an average of 18cm.

Visual summaries of the effect of LED module, LED flowering lamp and T LD treatments relative to the SD control, which flowered on average 101 days into treatment, are presented in figures 51, 52 and 53. Comparing LED module DE treatments and Tungsten DE; the 100% B and 100% R LED treatments were ineffective at hastening flowering; the FR containing and T treatments were all effective, flowering an average of 62-71 days into treatment (figure 51). As NB treatments, the most effective lamp type was T, with plants flowering on average 57 days into treatment; of the other LED modules 75%R+25%FR and 25%R+75%FR were more effective at hastening flowering than the 100% R and 100% FR treatments, which flowered 60-62 days and 86-71 days into treatment respectively (figure 52). The FR and DR/W/FR flowering lamps delivered as DE treatments reduced the time taken for plants to flower relative to the SD control (figure 53). Plants grown under DR/W/FR lamps flowered 57 days into treatment and is therefore, as effective as T NB at hastening flowering in pansy. The FR flowering lamp hastened flowering to the same extent as T DE, flowering 64 and 68 days into treatment, respectively. Plants grown under DR/W lamps flowered 98 days into treatments, which is comparable to the SD control.

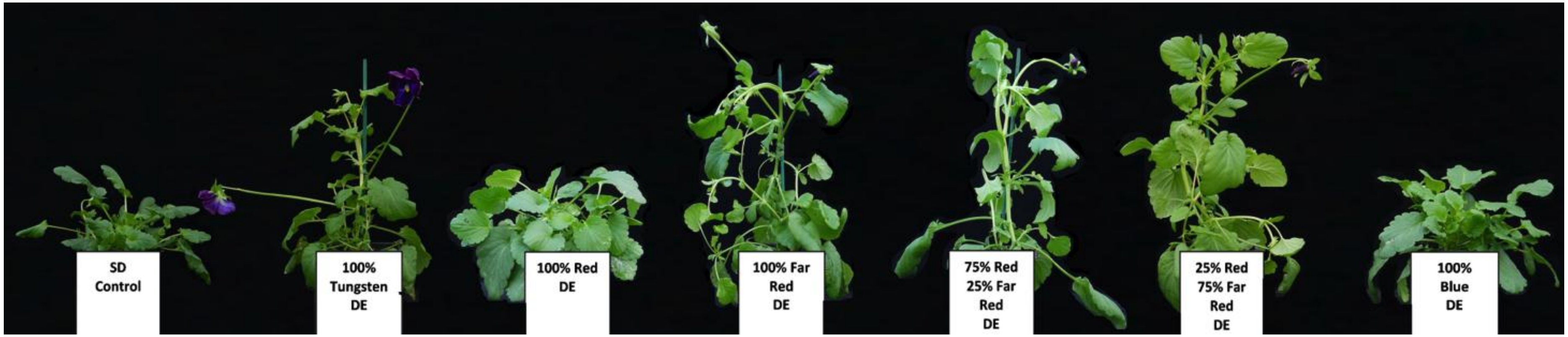


Figure 51. Pansy: The effect of DE lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

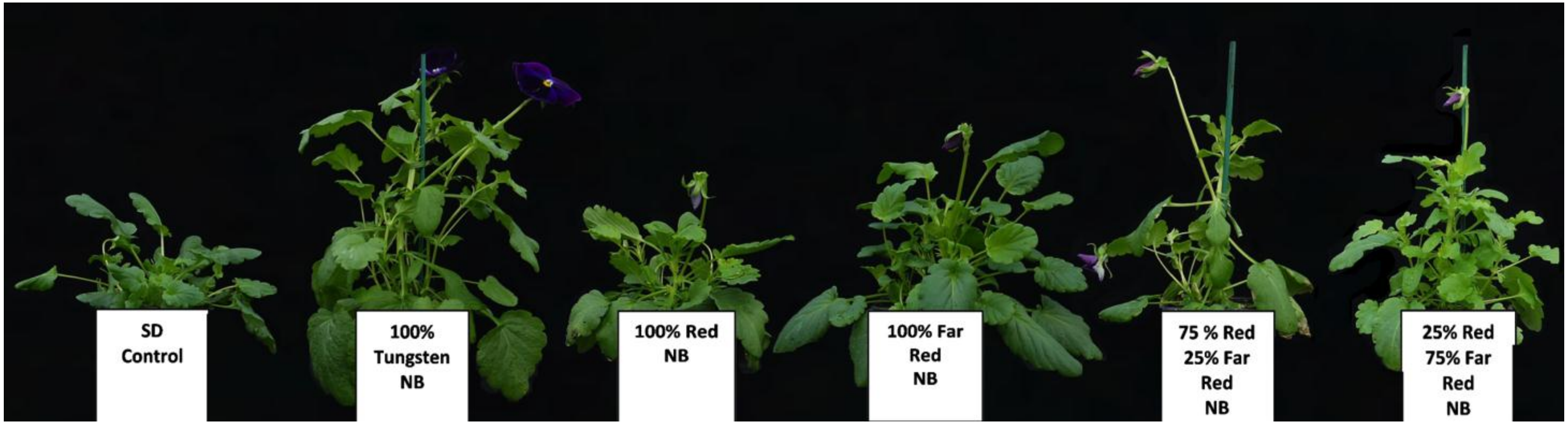


Figure 52. Pansy: The effect of NB lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

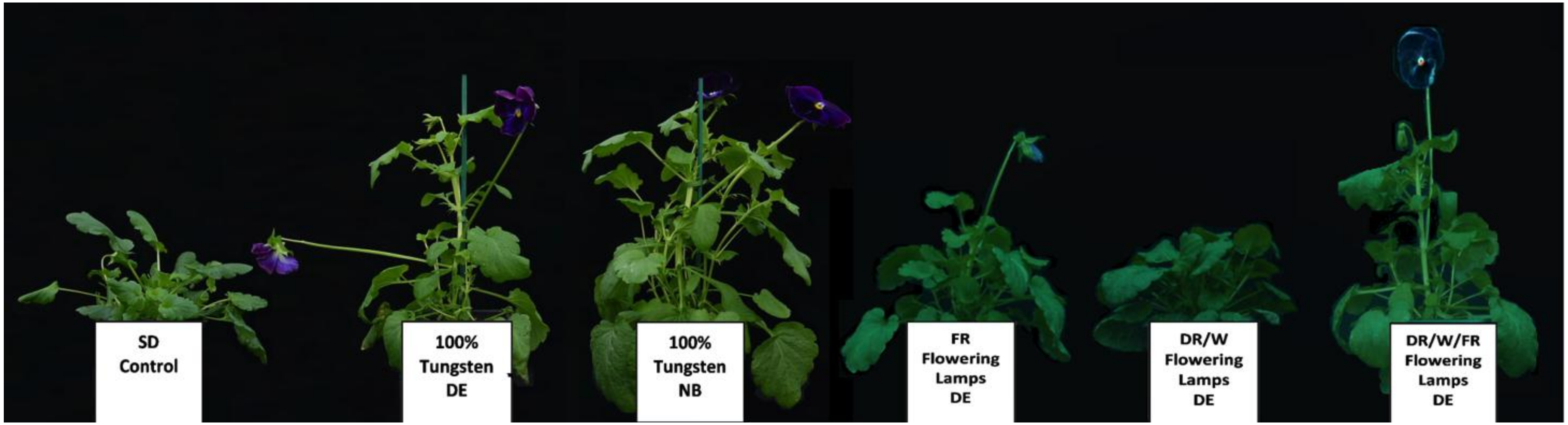


Figure 53. Pansy: The effect of DE lighting with different types of Philips GreenPower LED flowering lamps in comparison to T lamps (DE and NB) and a SD control.

Petunia Express Salmon

DE lighting with CF lamps hastened flowering of petunia (Express Salmon) when compared with the short day treatment. However, the lamps were not as effective as T, especially when used as a DE. The light spectrum from CF lamps did not match that from T lamps well enough to control flowering effectively for petunia.

Philips GreenPower LED Modules

Development of Visible Buds

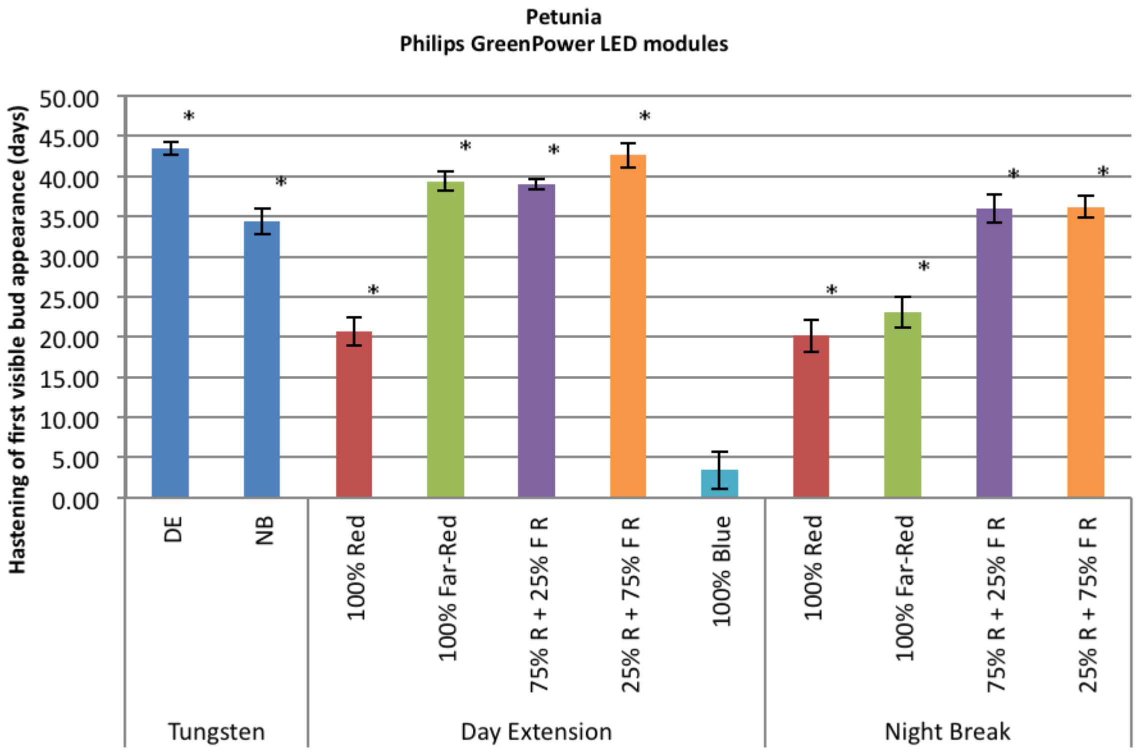


Figure 54. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB treatment, on the hastening of first visible bud appearance relative to the short day control, which has been set to 0. Error bars represent SE, LSD = 4.46 and * denotes a significant effect of light treatment on plant response.

Each of the LD treatments, with the exception of the 100% B LED modules, significantly ($p<0.05$) reduced the time taken for buds to develop compared to the SD control, where plants developed visible buds after an 80 days (figure 54). T DE was more effective than T NB, hastening the appearance of buds by 44 and 35 days, respectively. 100% FR and 25%R+75%FR treatments were also more effective when delivered as DE in comparison with the same NB treatments.

The DE treatments containing FR were statistically as effective at hastening bud development as T DE. 25%R+75%FR DE treatment produced buds on average 37 days into treatment, comparable to the hastening of bud development in plants under T DE, which also developed buds after 37 days in treatment.

Although they hasten the appearance of buds by approximately 20 days, 100% R DE and 100% R NB are the least effective LED module treatments. Tested here only as a DE treatment, 100% B LED modules proved ineffective at controlling flowering in petunia, with plants producing buds in 77 days, comparable to the 80 days in which the SD control plants produced buds.

Development of flowers from first visible bud

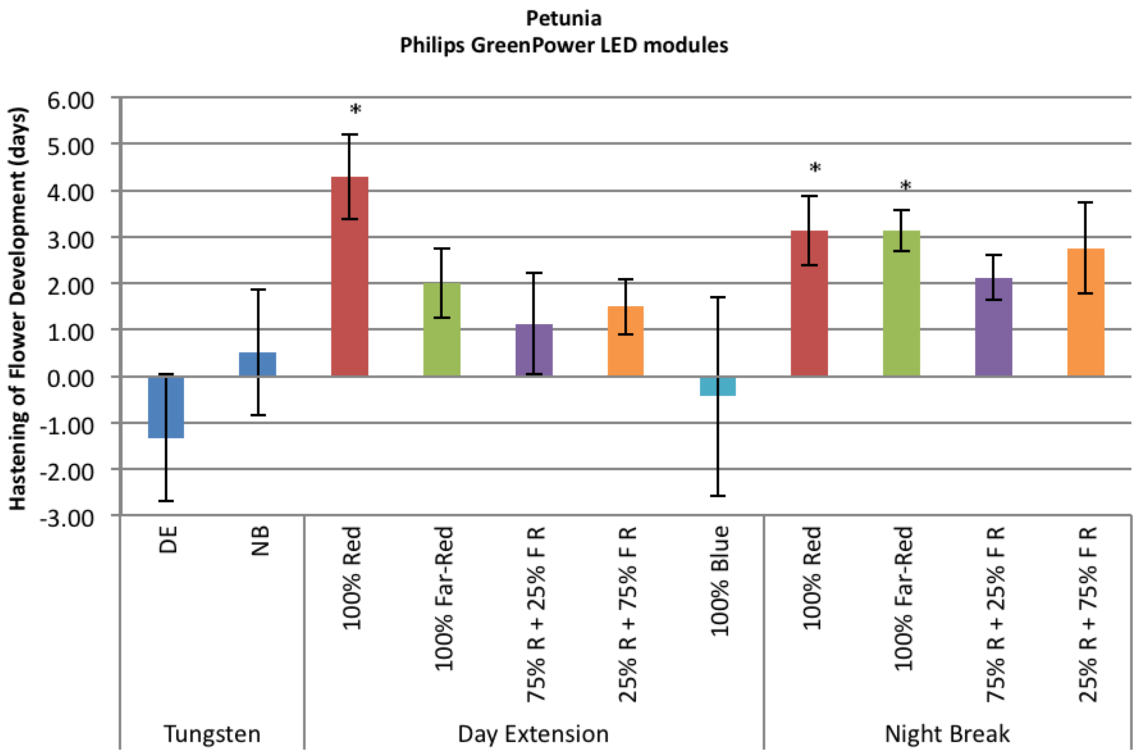


Figure 55. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB treatment, on number of days from bud to flower relative to the short day control. Error bars represent SE, LSD = 3.08 and * denotes a significant effect of light treatment on plant response.

Flower development time was variable across the LED module treatments, as indicated by the large error bars in figure 55; the only treatment to have a significant influence was 100% R DE. The other LD treatments tested here (figure 55) developed flowers 13-17 days after bud appearance, which is comparable to the 16 day average for the SD control.

Philips GreenPower LED Flowering Lamps

Development of Visible Buds

DE treatments by all three GreenPower LED flowering lamps were able to hasten the appearance of visible buds by 33-43 days, relative to the SD control (figure 56). Statistically, the DR/W lamp was the least effective, hastening development by an average of 33 days, comparable to the reduction in development time of 34 days induced by T NB. The DR/W/FR lamp was significantly ($p<0.05$) more effective than the other flowering lamps and statistically as effective as T DE, hastening bud development by 42-43 days.

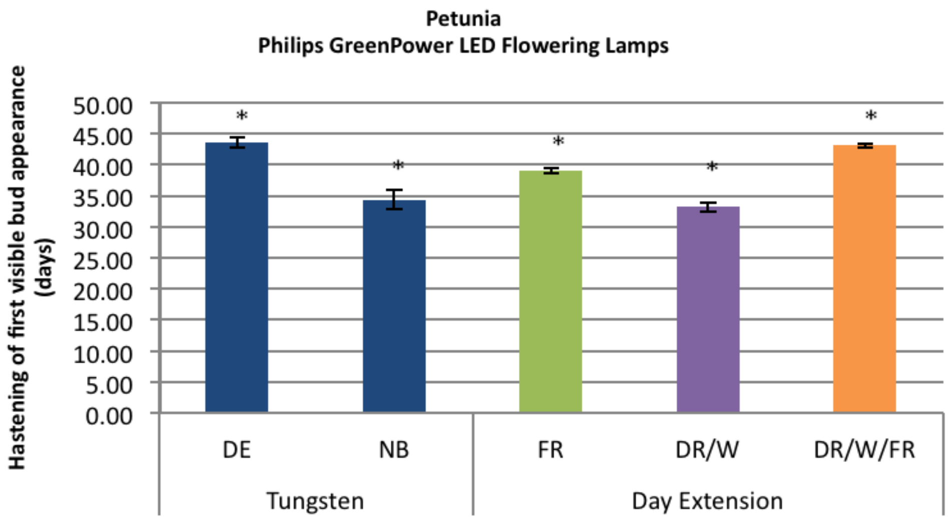


Figure 56. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on the hastening of first visible bud appearance relative to the short day control, which is set to 0. Error bars represent SE, LSD (T) = 3.69 / LSD (LED Flowering Lamps) = 2.86 and * denotes a significant effect of light treatment on plant response.

Development of flowers from first visible bud

FR and DR/W/FR lamps had a significant influence on the development of flowers from first visible bud relative to the SD control, hastening development by 1.9-2.4 days (figure 57). As with T DE and T NB, DR/W flowering lamp had no significant impact on flower development.

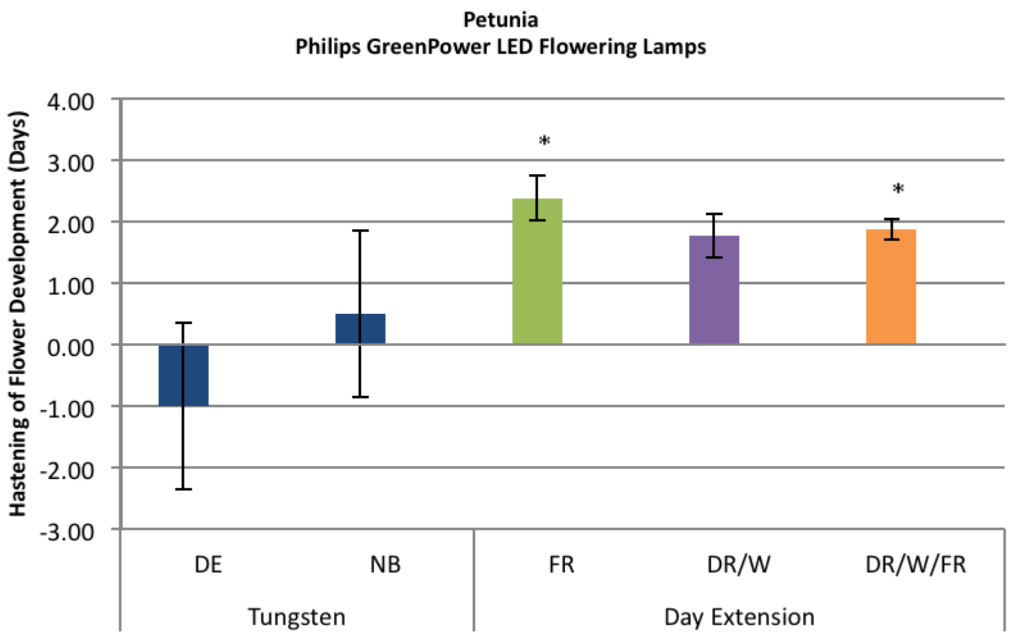


Figure 57. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on the hastening of flower development relative to the short day control, which is set to 0. Error bars represent SE, LSD (T) = 2.29 / LSD (LED Flowering Lamps) = 1.79 and * denotes a significant effect of light treatment on plant response.

Plant Height

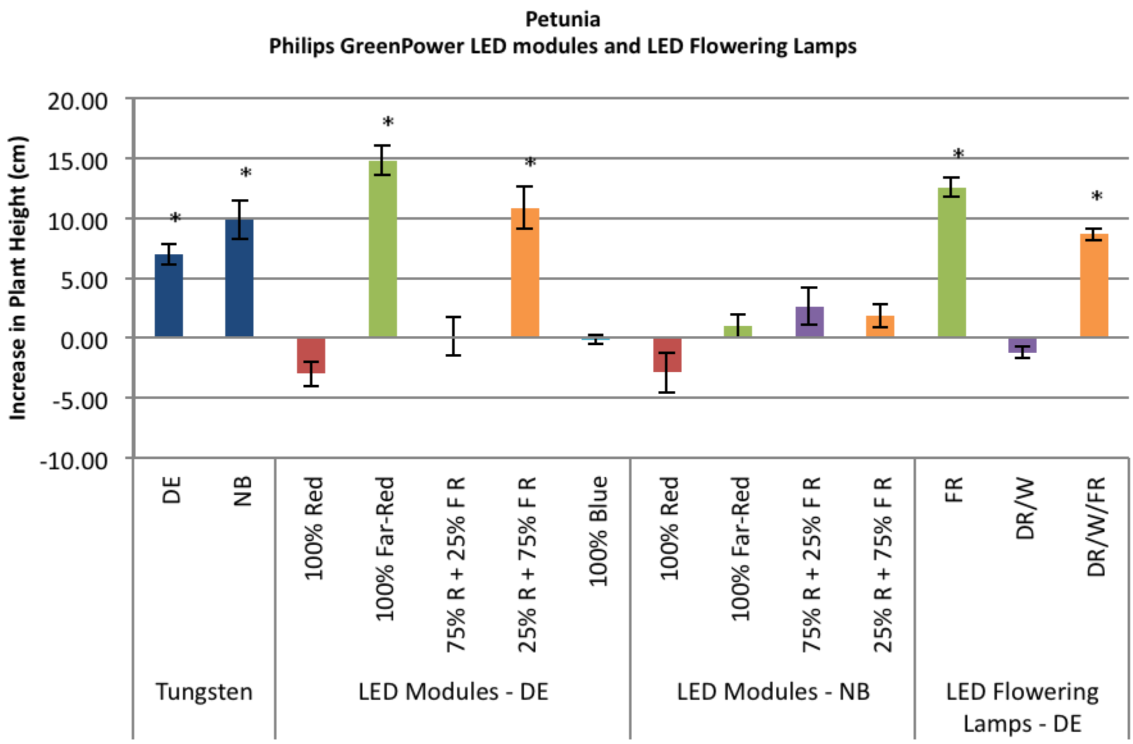


Figure 58. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on plant height relative to the short day control, which has been set to 0. Error bars represent SE, (LED Modules and T) = 3.71 / LSD (LED Flowering Lamps) = 2.87 and * denotes a significant effect of light treatment on plant response.

The effect of LED type on plant height was assessed relative to the SD control (figure 58). Plants under SD conditions were on average 34cm tall, both T DE and T NB treatments led to a significant increase in plant height of 7-10cm. The two LED module treatments (25%R + 75%FR and 100% FR) and two LED flowering lamp treatments (FR and DR/W/FR) that had a significant ($p<0.05$) impact on plant height were those that contained a larger proportion of FR and were delivered as DE treatments; these treatments led to an increase in plant height of 9-15cm.

Visual summaries of the effect of LED module, LED flowering lamp and T LD treatments relative to the SD control, which flowered on average 95 days into treatment, are presented in figures 59, 60 and 61. Comparing LED modules as DE treatments T, 25%R+75%FR and 100% FR were the most effective at hastening flowering of petunia (having developed open flowers 52-56 days into treatment) with 75%R+25%FR flowering slightly later (figure 59). As NB treatments 75%R+25%FR and 25%R+75%FR were as effective at hastening flowering as T, producing open flowers 57-61 days into treatment (figure 60). In comparing LED flowering lamp DE treatments, FR, DR/W/FR and Tungsten were equally as effective at hastening flowering (figure 61). Across both LED modules and LED flowering lamps, LD treatments containing far-red light are more effective at hastening flowering than those containing only R, B or DR/W.

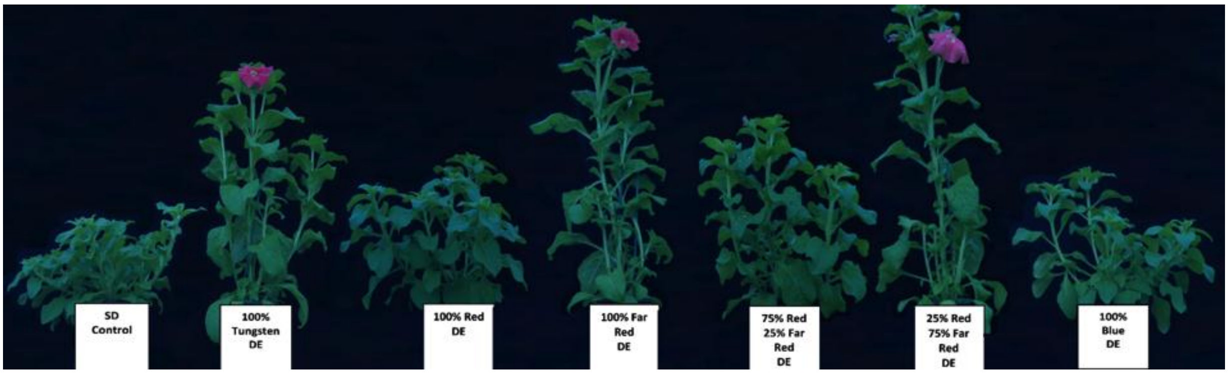


Figure 59. Petunia: The effect of DE lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

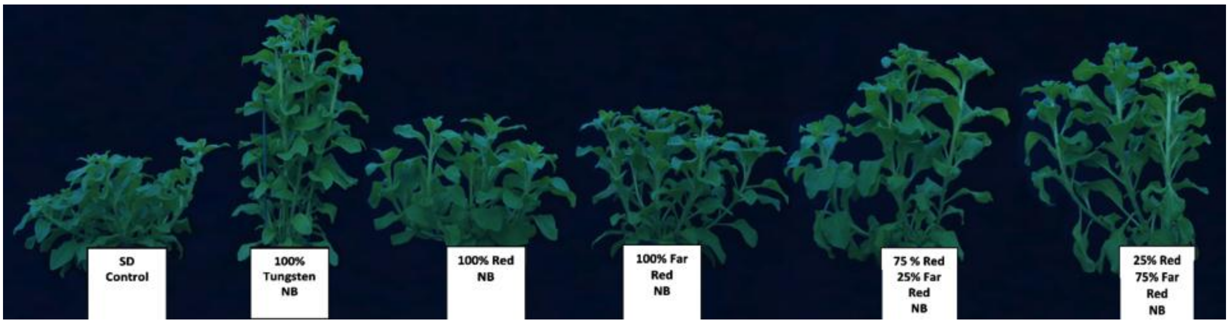


Figure 60. Petunia: The effect of NB lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

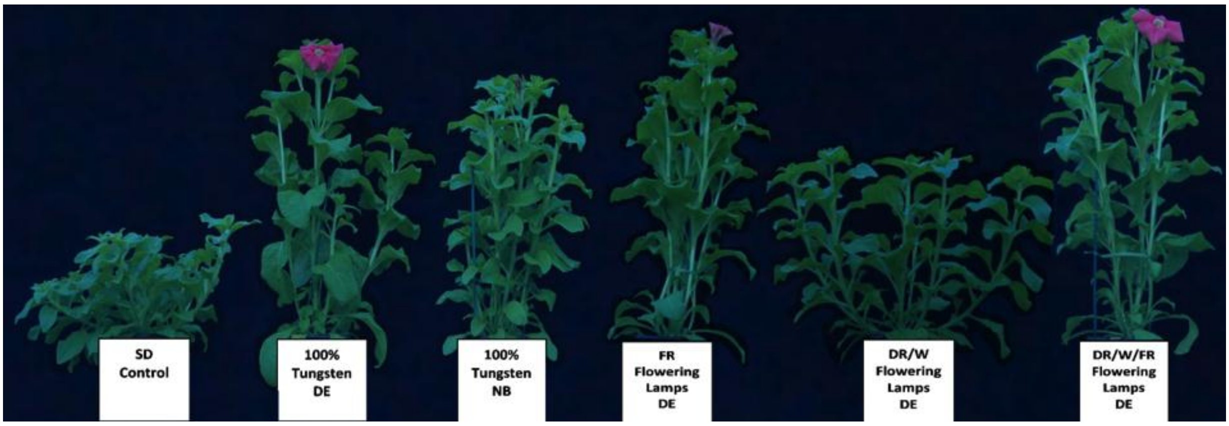


Figure 61. Petunia: The effect of DE lighting with different types of Philips GreenPower LED flowering lamps in comparison to T lamps (DE and NB) and a SD control.

Poinsettia Prestige Early Red

The first experiment demonstrated that for poinsettia (Prestige Early Red) CF lamps were able to delay the development of red bract stars. The plants had been kept for 26 weeks after pinching with red colour seen more frequently on those in CF DE treatment than either T DE or T NB, indicating a greater delay in colour development with T compared to CF. However, red bract development was controlled well enough by CF lighting for the effective commercial manipulation of day length.

Philips GreenPower LED modules

Development of red bracts

Plants developed red bracts/leaves 37 days from the start of treatments when grown in SD (figure 62). With the exception of 100% B DE, all LD treatments resulted in a significant ($p<0.05$) delay in the development of red colour and not all treatments had started to colour by the end of the experiment (156 days into treatment). Where red bracts had not developed, days to red bract development was set as 156 days, illustrating a delay in development of 119 days relative to the SD control (figure 62). The actual delay would have been longer than the data presented here, however, as these treatments resulted in a significant delay relative (of at least 119 days) they would all be effective in the manipulation of day length required in commercial poinsettia production.

The LD treatments 100% R DE, 100% FR DE, 25%R+75%FR DE and 100% FR NB all caused a significant delay in red bract development but were significantly less effective than the LD treatments which had not produced red bracts (T DE, T NB, 75%R+25%FR DE, 100% R NB, 75%R+25%FR NB and 25%R+75%FRNB). 100% B DE developed red bracts on average 40 days into treatment, comparable with plants grown in SDs.

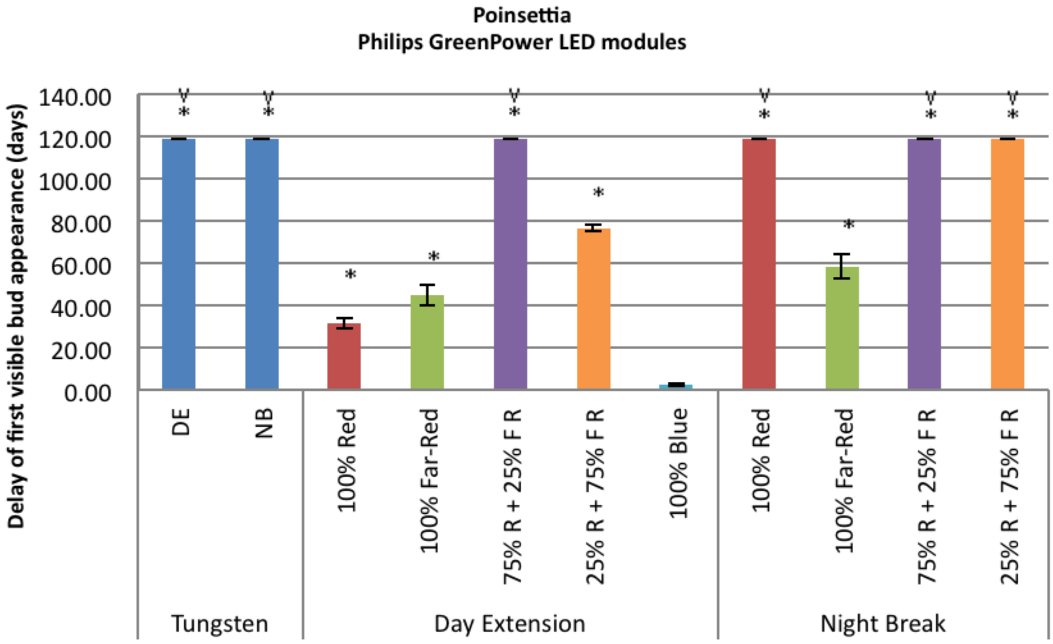


Figure 62. Comparing the effect of tungsten lamps with Philips GreenPower LED modules, using either DE or NB treatment, on the delay of first visible bud appearance relative to the short day control, which has been set to 0. Error bars represent SE, LSD = 6.14, * denotes a significant effect of light treatment on plant response and V denotes plants that remained vegetative after 156 days in treatment.

Plants in SD developed visible cyathia 80 days on average from the start of treatments. There was insufficient cyathia development in the LD treatments by the end of the experiment to carry out a balanced assessment. Similarly to plants in SDs, those under 100% B DE treatment developed cyathia on average 45 days after the development of red bracts. The 100% R DE and 100% FR DE and NB treatments, had the highest incidence of cyathia; cyathia development was delayed by around 30 days by 100% R DE, which developed cyathia 113 days into treatment; 100% FR NB was more effective at delaying cyathia development than 100% FR DE, which developed cyathia 140 and 115 days into treatment, respectively. The remaining LD treatments resulted in delays in excess of this level with some treatments yet to develop cyathia 156 days into treatment.

Philips GreenPower LED flowering lamps

Development of red bracts

Plants grown with T DE and T NB lamps had not developed red bracts 156 days into treatment resulting in a minimum delay of 119 days relative to the SD control. All three LED flowering lamps tested significantly delayed the development of red bracts. FR and DR/W flowering lamps resulted in delays of 50 and 58 days, respectively, with DR/W being more effective than the FR lamp (figure 63). Plants grown with DR/W/FR lamps had not developed red bracts by the end of the experiment and thus this treatment was significantly more effective than the other two flowering lamp types.

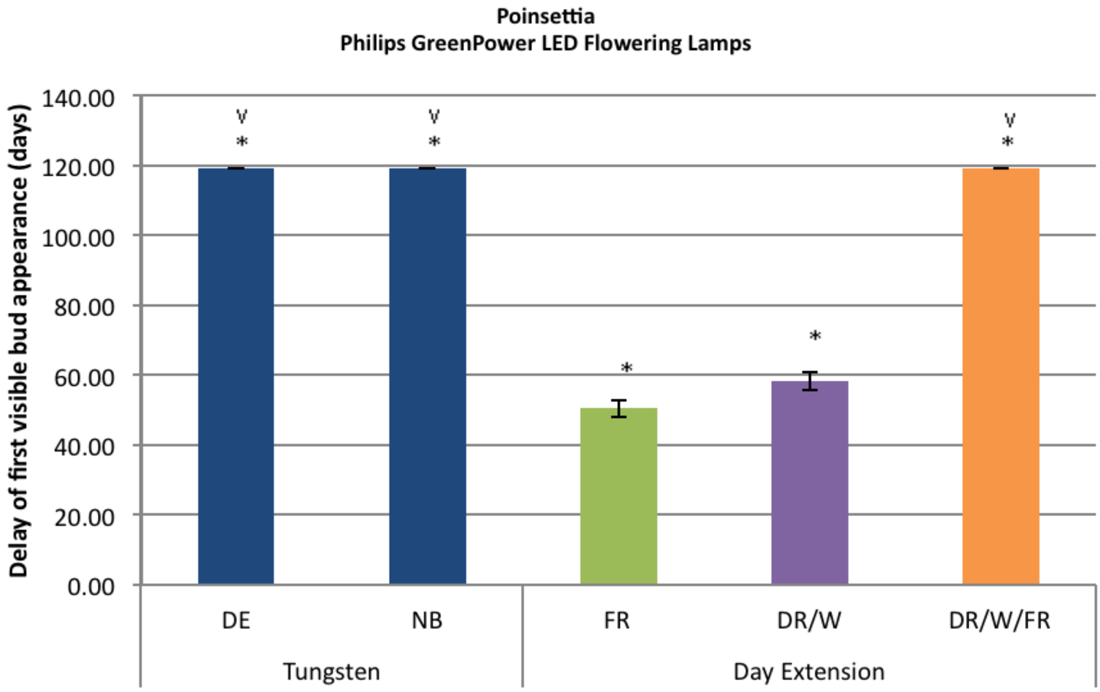


Figure 63. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on delaying bud appearance relative to the short day control, which has been set to 0. Error bars represent SE, LSD (T) = 8.40 / LSD (LED Flowering Lamps) = 6.83, * denotes a significant effect of light treatment on plant response and V denotes plants that remained vegetative after 156 days in treatment.

There was insufficient cyathia development in the LED flowering lamp LD treatments by the end of the experiment to carry out a balanced assessment. The only flowering lamp to develop cyathia within the timeframe of the experiment was FR, which developed cyathia 132 days into treatment - delaying development by around 50 days relative to the SD control. Plants grown with DR/W or DR/W/FR lamps were yet to develop cyathia 156 days into treatment.

Plant Height

Figure 64 illustrates the impact of LD treatments on increasing plant height in poinsettia relative to plants grown in SDs, which were 13cm tall, on average. The 100% B DE LED module treatment had no significant impact when compared to the SD control, producing plants of an average height of 14cm. The remaining LD treatments resulted in significant increases in plant height of 6-15cm. LED treatments containing high proportions of far-red light cause greater increases in plant height relative to the SD control; plants grown with 25%R+75%FR DE treatment were significantly taller than those in any other treatments.

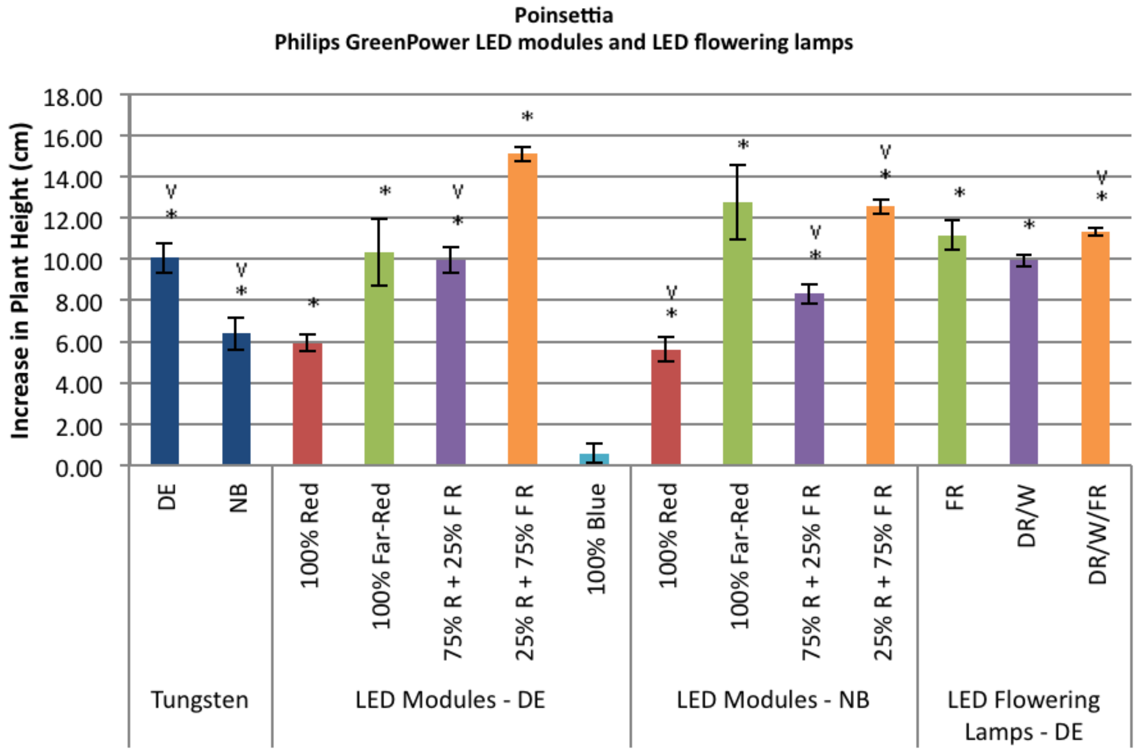


Figure 64. Comparing the effect of tungsten lamps (DE or NB) with Philips GreenPower LED flowering lamps (DE), on plant height relative to the short day control, which has been set to 0. Error bars represent SE, LSD (LED Modules and T) = 2.33 / LSD (LED Flowering Lamps) = 1.89, * denotes a significant effect of light treatment on plant response and V denotes plants that remained vegetative after 156 days in treatment.

Visual summaries of the effect of LED module, LED flowering lamp and T LD treatments relative to the SD control, which produced the earliest development of red colour, 37 days into treatment, and subsequent cyathia development, 80 days into treatment, are presented in figures 65, 66 and 67. Comparing LED modules as DE treatments, 100% B, which developed red bracts after 40 days, was the only ineffective treatment for delaying the development of red bracts (figure 65). T DE and 25%R+75%FR DE were most effective as neither treatment had developed red bracts at the end of the experiment. As NB treatments, all LED modules were effective at delaying colour development, as 75%R+25%FR was the only NB treatment to have developed red bract prior to the completion of the experiment (figure 66). Figure 67 illustrates that all three flowering lamps tested as DE treatments were effective for delaying the development of red bracts; FR flowering lamps were the least effective, developing colour 87 days into treatment.

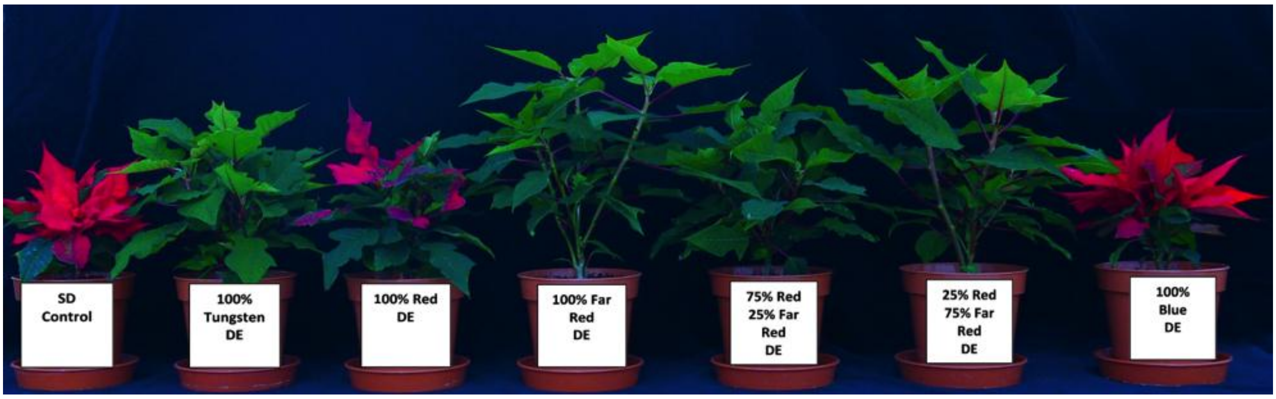


Figure 65. Poinsettia: The effect of DE lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

Figure 66. Poinsettia: The effect of NB lighting with different combinations of Philips GreenPower LED modules in comparison to T lamps and a SD control.

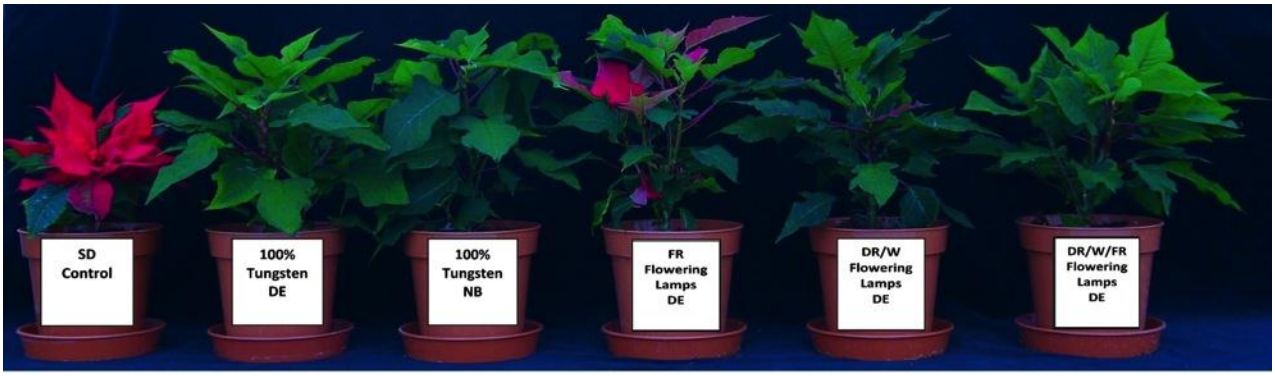


Figure 67. Poinsettia: The effect of DE lighting with different types of Philips GreenPower LED flowering lamps in comparison to T lamps (DE and NB) and a SD control.

Discussion

The data included in this report for the development of buds, and subsequently flowers, is based on definitions for these stages (as outlined in Appendix I) which form a reproducible and robust measure of a set stage but may be different to stages defined in commercial marketing specifications. For example, it is likely that our visible bud stage is earlier than might be the case for commercial marketing of plants since our definition is based on the earliest positive sign of budding on a plant rather than more advanced budding which may be visible on the majority of shoots across the whole of a plant. Furthermore the timings are based on time in treatments, which for the majority of species started at the potting on stage (i.e. for either rooted cuttings or plug plants). However, Christmas Cactus were partially grown in commercial conditions prior to starting treatments which means time to flowering in treatments will appear shorter than might be expected from commercial experience. Poinsettias were also grown in LD following potting and prior to starting treatments in order to increase plant size prior to inducing flowering.

The first stage of this project concluded that there was no single CF solution which would have satisfied the needs of all species when replacing tungsten lighting to manipulate photoperiod. It had also not been possible to generalise according to whether the crop had a SD or LD response. Plant response to CF indicated that the solution to inducing a more effective response would be to change the spectral output rather than increasing intensity by increasing the number of lamps used, because where CF lamps were not effective, increasing the light level up to 9.3µmol $m^{-2}s^{-1}$ was not sufficient to improve the response. Therefore, the second stage of the project focussed on using LED modules and LED flowering lamps to deliver different light qualities in order to identify one that would be suitable for controlling flowering in a range of species. Commercially available Philips LED light systems have been tested in order to produce useable recommendations for growers as they are being developed for the Horticultural industry. LED lights are available from other suppliers however these have not been tested.

In the previous experiment three of the short day species responded well to CF LD treatments. In the second stage of experiments the same three species responded well to the DR/W/FR Philips GreenPower LED flowering lamp. When given a DE treatment with DR/W/FR LED flowering lamps, the flowering of **chrysanthemum** (Tampico White) and **poinsettia** (Prestige Early Red) and the tuber development of **begonia** (Illumination Rose) was delayed to the same extent as T (both DE and NB). Thus, suggesting that for these species DR/W/FR flowering lamps have a spectral output that matches T. However, for **Christmas cactus** (olga) all three of the LED flowering lamps tested, FR, DR/W and DR/W/FR, caused a delay in flowering equivalent to T NB but T DE resulted in the greatest delay (which was a continuation of the treatment these plants had received during initial production at commercial nursery). In addition to DR/W/FR, the DR/W LED flowering lamp treatment delayed flowering in **chrysanthemum,** as plants grown under both lamp types had not produced visible buds by the end of the experiment.

The response of LD species to CF lighting was more varied than for SD species in the previous experiment. Across the LD species tested the response to Philips GreenPower LED flowering lamps was more uniform; both DR/W/FR and FR treatments hastened flowering for **antirrhinum** (Red Bells), **lisianthus** (Florida Silver), **pansy** (Majestic Giant Purple) and **petunia** (Express Salmon) to the same extent as T DE, which was more effective than T NB for antirrhinum and petunia.

In considering the replacement of T lighting using Philips LED flowering lamps for controlling flowering by manipulating photoperiod; DR/W/FR would be effective for the SD species (with the exception of Christmas cactus) and DR/W/FR or FR would be effective for the LD species. Suggesting that for these lamps, DR/W/FR may serve as a suitable replacement for T for the majority of the species tested here.

In general, for Philips GreenPower LED modules, combinations of R (~660nm) and FR (~730nm) light were the most effective LD treatments for delaying flowering in SD species and hastening flowering in LD species. Which light quality and type of LD treatment was most effective varied between species and appears to be species specific.

The response to 25%R+75%FR DE was equivalent to the most effective T treatment for all LD species tested; **antirrhinum** (Bells Red), **lisianthus** (Florida Silver), **pansy** (Majestic Giant Purple) and **petunia** (Express Salmon). In general, for antirrhinum and petunia, the LED modules were more effective at hastening flowering as DE rather than NB treatments, which was also demonstrated in these species for the T LD treatments. Therefore, for these LD species 25%R+75%FR DE would provide a single solution for manipulating photoperiod. It should be noted that other LED module combinations were effective at hastening flowering for these four species, for example, 75%R+25%FR NB and 25%R+75%FR NB were equally as effective as 25%R+75%FR DE for pansy.

The response of SD species to the LED modules tested was more variable than the LD species and so it is more difficult to establish a single LED module type or combination that will be suitable. For **chrysanthemum** (Tampico White), **begonia** (Illumination Rose) and **poinsettia** (Prestige Early Red) 75%R+25%FR DE was equally as effective as T DE and T NB treatments at delaying SD responses. Different LED module combinations were also effective, although these varied between species; 100% R DE and R/FR mixtures, given as both DE and NB, were effective at decreasing tuber fresh weight in begonia; 100% R and R/FR mixtures, both DE and NB, had not produced buds by the end of the experiment and thus were effective at delaying flowering in chrysanthemum; 75%R+25%FR DE, 100% R NB, 75%R+25%FR NB and 25%R+75%FR NB were effective at delaying SD response in poinsettia. Although, 75%R+25%FR DE was a significantly effective LD treatment for delaying flowering in Christmas cactus, 25%R+75%FR DE was equivalent to T DE (which was more effective than T NB). Therefore, for Christmas cactus, where LED flowering lamps were unable to control flowering to the same extent as T DE, the 25%R+75%FR DE was a suitable alternative.

The 100% B LED modules, tested as a DE treatment, were generally ineffective across both SD and LD species. All of the SD species showed no significant difference in response between the 100% B and the SD treatments. Of the LD species; lisianthus and petunia showed no significant difference in response between the 100% B and the SD treatments; for antirrhinum and pansy where there was a significant difference between the 100% B and the SD treatments, the 100% B LED module was among the least effective treatments for these species. Therefore, B LEDs would not serve as an appropriate replacement for T lighting.

For the purposes of producing a single suitable replacement for T lighting, it is apparent that for LD species the LED module treatments containing 75%FR were effective at manipulating photoperiod, however, those treatments containing 25%R were effective at manipulating photoperiod for SD species (with the exception of Christmas cactus). Therefore, for the combinations of LED module tested here recommendations can be made on the basis of LD or SD response but it is not possible to recommend a single spectral output for this range of species.

Conclusions

The impact of different combinations of R and FR light indicate that spectral output is the dominant factor when controlling flowering and that a suitable light quality could be found for each of the individual species tested. Suggestions can be made based on flowering control; both SD and LD species (with the exception of Christmas cactus) could be effectively controlled by DR/W/FR LED flowering lamps; LD species and Christmas cactus could be effectively controlled by a 25%R+75%FR DE LED module treatment; and SD species (with the exception of Christmas cactus) could be controlled effectively by 75%R+25%FR DE. However, suggesting a suitable light quality to control flowering in a range of species becomes complicated when considering the developmental and morphological differences that were observed between the treatments. A significant amount of stretching occurred as a consequence of treatments with high proportions of far-red light. In particular, those containing 75% or 100% FR resulted in large increases in plant height relative to the SD control. Plant height of Christmas cactus was not affected by lamp type, however, this species was not in treatment very long before flowering and so other species were exposed to lighting treatments for a longer period. A balance must be established between manipulating photoperiod and reducing any unfavourable physical effects on plant species to ensure commercially viable plants are produced.

Although each species appears to have a subtly different optimum, all those tested responded well to a mixture of R and FR light, which reinforces the idea that CF lamps may not be an appropriate replacement for T lighting as they have a very low FR output. Generally, of the treatments tested 25%R+75%FR DE gave good control and reduced stretching for the majority of species however, 75%FR+25%R DE gave better control of flowering but resulted in large increases in plant height. Therefore, a 50%R+50%FR LED module treatment may be ideal, minimising stretching as a result of far-red but further experimentation would be required to ensure that flowering control would not be compromised. It is also possible that using a combination of LED flowering lamps, rather than one type as tested here, may deliver an appropriate light spectrum.

Long term, LED lighting may well be the preferable alternative to T lighting because of the potential to adjust spectral output. In addition, as high light levels are not required and LEDs only provide light in the desired part of the spectrum they are much more energy efficient. It is therefore more likely that with further investigation on a wider range of plant species a suitable solution will be established, whether that be for groups or individual plant species. This project has demonstrated the importance of FR light in the control of flowering and considering the very low FR output of CF lamps and their inability to control flowering in over half of the species tested in the first stage of the project, they do not seem to be a dependable alternative to T. Although the initial capital costs are higher for the installation of LEDs, their efficiency coupled with their long operating life given rising costs of energy would be highly beneficial to commercial growers. It should also be noted that the Philips LED flowering lamps are able to fit into existing tungsten festoon lighting setups although they are only available in screw fittings. Companies are developing other LED systems, for example, SolarOasis have developed both the GrowStar Pro550 (a broad spectrum solid state LED plant grow light) and monochrome LED clusters (a research and development tool available in 22 wavelengths). As more LED systems become available there are likely to be significant reductions in cost.

It would also be useful for any subsequent experiments to investigate the impact of giving light treatments at different times, for example, pre-dawn DE LED lighting treatments, and whether the lighting treatments that proved effective in this stage of the project could be refined by light cycling in order to minimise operational costs.

Knowledge and Technology Transfer

New lamps for old! Replacing the tungsten bulb. HDC News, July/August 2012

HDC/ BPOA Poinsettia meeting, 17 January 2012, Warwick Crop Centre, Wellesbourne.

Appendix I: Definition of Bud and Flower stages

Anthirrinum

Buds: 1-2 mm diameter

Flower: As soon as inside of flower is visible

Petunia

Buds: 2-3 mm diameter

Flower: As soon as inside of flower is visible

Pansy

Buds: approx. 7 mm long

Flower: As soon as inside of flower is visible

Chrysanthemum

Buds: 4 mm diameter

Flower: Flower stage 6

Christmas cactus

Buds: 1-2 mm long

Flower: As soon as pink stigma is visible

Poinsettia

Red colour: As soon as visible

Cyathia: Recorded as soon as leaves unfolded

Lisianthus

Buds: Approx. 5mm long

Begonia

Buds: 8-10mm long

Appendix II: Photoperiod Cabinet data – Philips GreenPower LED Modules

Antirrhinum (Bells Red)

Antirrhinum: Days to visible bud	Long Day Treatment and Lamp Type											
		Tungsten		Day Extension					Night Break			
	Short Day Control	DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	48.13	30.13	37.14	52.75	32.75	31.63	27.75	39.86	46.00	36.38	35.88	35.25
St Dev	2.30	2.10	5.01	2.10	3.11	2.13	2.96	2.73	6.00	3.50	5.14	5.06
St Error	0.81	0.74	1.90	0.74	1.10	0.75	1.05	1.03	2.12	1.24	1.82	2.53
No. Reps	8	8	7	8	8	8	8	7	8	8	8	4

Antirrhinum: Days from visible bud to open flower	Long Day Treatment and Lamp Type											
		Tungsten		Day Extension					Night Break			
	Short Day Control	DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	28.50	23.17	26.43	38.50	23.63	23.88	22.25	27.71	29.38	26.25	26.50	24.75
St Dev	0.93	1.16	2.15	12.22	2.13	1.13	1.75	0.76	3.20	2.43	1.85	0.96
St Error	0.33	0.41	0.81	4.32	0.75	0.40	0.62	0.29	1.13	0.86	0.65	0.48
No. Reps	8	8	7	8	8	8	8	7	8	8	8	4

Begonia (Illumination Rose)

Begonia: Tuber Fresh Weight (g)	Long Day Treatment and Lamp Type										
		Tungsten		Day Extension				Night Break			
	Blue	DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	9.01	3.23	4.27	2.65	4.48	3.74	3.14	3.86	5.32	3.24	3.33
St Dev	3.61	1.76	1.50	1.26	1.51	1.36	0.51	1.17	1.86	1.42	1.05
St Error	2.55	0.62	0.53	0.44	0.57	0.48	0.19	0.41	0.66	0.50	0.37
No. Reps	2	8	8	8	7	8	7	8	8	8	8

Begonia: Tuber Diameter (mm)	Long Day Treatment and Lamp Type										
		Tungsten		Day Extension				Night Break			
	Blue	DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	25.05	18.08	20.11	13.51	17.90	16.50	16.87	18.79	20.96	16.55	17.63
St Dev	5.50	4.09	2.69	3.82	3.39	2.93	2.96	1.88	3.18	4.15	2.88
St Error	3.89	1.45	0.95	1.44	1.28	1.04	1.12	0.66	1.13	1.47	1.02
No. Reps	2	8	8	7	7	8	7	8	8	8	8

Begonia: Total Fresh Weight (g)	Long Day Treatment and Lamp Type										
		Tungsten		Day Extension				Night Break			
	Blue	DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	16.37	77.94	78.99	74.17	52.22	65.34	54.99	59.32	55.87	61.22	61.31
St Dev	6.70	39.39	30.76	27.57	18.33	29.27	23.88	8.56	25.42	33.10	21.65
St Error	4.74	13.93	10.87	10.42	6.48	10.35	8.44	3.03	8.99	11.70	7.65
No. Reps	2	8	8	7	8	8	8	8	8	8	8

Begonia: Days to visible bud	Long Day Treatment and Lamp Type										
		Tungsten		Day Extension				Night Break			
	Blue	DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	129.00	91.75	90.63	89.00	91.71	92.38	94.00	92.75	87.63	91.63	89.75
St Dev	0.00	10.39	5.68	3.02	6.10	5.21	8.25	8.91	2.13	6.97	2.55
St Error	0.00	3.67	2.01	1.07	2.31	1.84	3.12	3.15	0.75	2.46	0.90
No. Reps	2	8	8	8	7	8	7	8	8	8	8

Christmas cactus (Olga)

Christmas Cactus: Days to visible bud	Long Day Treatment and Lamp Type												
		Tungsten		Day Extension					Night Break				
	Short Day Control	DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	
Mean	12.75	30.50	18.29	16.00	25.17	26.83	31.33	13.38	19.13	13.88	17.13	14.75	
St Dev	2.19	6.35	5.02	6.23	4.62	6.01	2.58	3.16	4.05	4.19	4.61	5.99	
St Error	0.77	2.59	1.90	2.20	1.89	2.46	1.05	1.12	1.43	1.48	1.63	2.12	
No. Reps	8	6	7	8	6	6	6	8	8	8	8	8	

Christmas Cactus: Days from visible bud to open flower	Long Day Treatment and Lamp Type											
		Tungsten		Day Extension					Night Break			
	Short Day Control	DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	54.00	50.67	50.14	50.63	50.67	52.17	49.50	53.00	51.38	51.00	49.13	46.63
St Dev	1.93	5.16	3.08	2.83	1.37	5.31	2.35	2.73	2.26	3.66	1.73	4.63
St Error	0.68	2.11	1.16	1.00	0.56	2.17	0.96	0.96	0.80	1.30	0.61	1.64
No. Reps	8	6	7	8	6	6	6	8	8	8	8	8

Chrysanthemum (Tampico White)

Chrysanthemum: Days to visible bud	Long Day Treatment and Lamp Type											
		Tungsten		Day Extension					Night Break			
	Short Day Control	DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	29.50	91.00	91.00	91.00	81.33	91.00	91.00	30.13	91.00	68.25	91.00	91.00
St Dev	3.02	0.00	0.00	0.00	6.98	0.00	0.00	2.47	0.00	6.92	0.00	0.00
St Error	1.07	0.00	0.00	0.00	2.85	0.00	0.00	0.88	0.00	2.45	0.00	0.00
No. Reps	8	8	8	8	6	8	8	8	8	8	8	8

Chrysanthemum: Leaf Number	Long Day Treatment and Lamp Type											
		Tungsten		Day Extension					Night Break			
	Short Day Control	DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	12.00	25.13	22.25	20.25	22.67	23.38	23.50	12.38	22.13	17.63	21.63	22.13
St Dev	1.07	1.73	1.04	1.04	1.37	2.62	1.51	1.51	1.89	1.85	1.19	1.13
St Error	0.38	0.61	0.37	0.37	0.56	0.92	0.53	0.53	0.67	0.65	0.42	0.40
No. Reps	8	8	8	8	6	8	8	8	8	8	8	8

Lisianthus (Florida Silver)

Lisianthus: Days to visible bud	Long Day Treatment and Lamp Type											
		Tungsten		Day Extension					Night Break			
	Short Day Control	DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	156.00	139.00	139.67	156.00	141.00	156.00	137.33	156.00	156.00	145.67	142.33	139.00
St Dev	0.00	0.00	10.97	0.00	5.94	0.00	8.59	0.00	0.00	4.04	6.03	0.00
St Error	0.00	0.00	6.33	0.00	2.97	0.00	3.51	0.00	0.00	2.33	3.48	0.00
No. Reps	7	2	3	8	4	8	6	8	8	3	3	2

Pansy (Majestic Giant Purple)

Pansy: Days to visible bud	Long Day Treatment and Lamp Type											
		Tungsten		Day Extension					Night Break			
	Short Day Control	DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	81.43	37.00	35.63	76.88	45.00	46.71	40.75	66.13	47.38	47.88	39.88	40.75
St Dev	4.28	5.07	3.89	5.07	14.39	15.21	5.80	23.41	7.44	6.01	8.01	3.81
St Error	1.62	1.79	1.38	1.79	5.09	5.75	2.05	8.28	2.63	2.13	2.83	1.35
No. Reps	7	8	8	8	8	7	8	8	8	8	8	8

Pansy: Days from visible bud to open flower	Long Day Treatment and Lamp Type												
	Short Day Control	Tungsten		Day Extension					Night Break				
		DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	19.86	25.25	21.75	19.88	26.38	22.57	22.00	31.63	32.00	37.63	22.00	19.13
St Dev	1.46	10.08	3.41	4.05	7.23	8.22	3.82	18.84	10.41	10.84	4.66	2.47
St Error	0.55	3.56	1.21	1.43	2.56	3.11	1.35	6.66	3.68	3.83	1.65	0.88
No. Reps	7	8	8	8	8	7	8	8	8	8	8	8

Petunia (Express Salmon)

Petunia: Days to visible bud	Long Day Treatment and Lamp Type											
	Short Day Control	Tungsten		Day Extension					Night Break			
		DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	80.13	36.63	45.75	59.43	40.75	41.13	37.50	76.71	60.00	57.13	44.13	44.00
St Dev	3.76	2.33	4.40	4.76	3.41	1.89	4.41	6.68	5.83	5.46	5.00	3.93
St Error	1.33	0.82	1.56	1.80	1.21	0.67	1.56	2.36	2.06	1.93	1.77	1.39
No. Reps	8	8	8	7	8	8	8	8	8	8	8	8

Petunia: Days from visible bud to open flower	Long Day Treatment and Lamp Type											
	Short Day Control	Tungsten		Day Extension					Night Break			
		DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	16.00	17.00	15.50	11.71	14.00	14.88	14.50	16.43	12.88	12.88	13.88	13.25
St Dev	4.21	3.85	3.82	2.43	2.14	3.09	1.69	5.65	2.10	1.25	1.36	2.76
St Error	1.49	1.36	1.35	0.92	0.76	1.09	0.60	2.14	0.74	0.44	0.48	0.98
No. Reps	8	8	8	7	8	8	8	7	8	8	8	8

Poinsettia (Prestige Early Red)

Poinsettia: Days to first red bract	Long Day Treatment and Lamp Type											
	Short Day Control	Tungsten		Day Extension					Night Break			
		DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR
Mean	37.00	156.00	156.00	68.25	81.83	156.00	113.67	39.50	156.00	95.38	156.00	156.00
St Dev	2.78	0.00	0.00	6.94	11.55	0.00	3.56	2.33	0.00	16.25	0.00	0.00
St Error	0.98	0.00	0.00	2.45	4.71	0.00	1.45	0.82	0.00	5.74	0.00	0.00
No. Reps	8	6	7	8	6	6	6	8	8	8	8	8

Appendix III: Festoon Lighting Data – Philips GreenPower LED Flowering Lamps

Antirrhinum (Bells Red)

Antirrhinum: Days to visible bud	Long Day Treatment and Lamp Type					
		Tungsten		Day Extension		
	Short Day Control	DE	NB	FR	DR/W	DR/W/FR
Mean	48.13	30.13	37.14	28.92	37.11	29.15
St Dev	2.30	2.10	5.01	1.77	3.23	2.92
St Error	0.81	0.74	1.90	0.28	0.54	0.46
No. Reps	8	8	7	39	36	40

Antirrhinum: Days from visible bud to open flower	Days from Visible Bud to Open Flower					
		Tungsten		Day Extension		
	Short Day Control	DE	NB	FR	DR/W	DR/W/FR
Mean	28.50	23.25	26.43	21.41	27.03	21.68
St Dev	0.93	1.16	2.15	1.15	1.39	1.64
St Error	0.33	0.41	0.81	0.18	0.23	0.26
No. Reps	8	8	7	39	36	40

Begonia (Illumination Rose)

Begonia: Tuber Fresh Weight (g)	Long Day Treatment and Lamp Type					
		Tungsten		LED Flowering Lamps - Day Extension		
	Blue LED Module	DE	NB	FR	DR/W	DR/W/FR
Mean	9.01	3.23	4.27	5.16	5.21	3.15
St Dev	3.12	1.76	1.50	2.41	2.64	1.61
St Error	2.21	0.62	0.53	0.54	0.59	0.36
No. Reps	2	8	8	20	20	20

Begonia: Tuber Diameter (mm)	Long Day Treatment and Lamp Type					
		Tungsten		LED Flowering Lamps - Day Extension		
	Blue LED Module	DE	NB	FR	DR/W	DR/W/FR
Mean	25.05	17.53	20.11	20.79	22.75	18.10
St Dev	4.46	4.09	2.69	4.22	4.80	3.66
St Error	3.15	1.45	0.95	0.94	1.07	0.82
No. Reps	2	8	8	20	20	20

Begonia: Total Fresh Weight (g)	Long Day Treatment and Lamp Type					
		Tungsten		LED Flowering Lamps - Day Extension		
	Blue LED Module	DE	NB	FR	DR/W	DR/W/FR
Mean	16.37	77.59	78.99	47.58	88.60	69.34
St Dev	7.77	39.39	30.76	22.16	25.44	28.12
St Error	5.50	13.93	10.87	4.96	5.69	6.29
No. Reps	2	8	8	20	20	20

Begonia: Days to visible bud	Days to Visible Bud					
		Tungsten		LED Flowering Lamps - Day Extension		
	Blue Only LED	DE	NB	FR	DR/W	DR/W/FR
Mean	129.00	91.75	90.63	96.68	92.48	92.83
St Dev	0.00	10.39	5.68	7.99	6.63	6.30
St Error	0.00	3.67	2.01	1.26	1.05	1.00
No. Reps	8	8	8	40	40	40

Christmas cactus (Olga)

Christmas Cactus: Days to visible bud	Long Day Treatment and Lamp Type					
		Tungsten		Day Extension		
	Short Day Control	DE	NB	FR	DR/W	DR/W/FR
Mean	12.75	30.50	18.29	19.08	21.64	20.67
St Dev	2.19	6.35	5.02	5.27	6.03	6.38
St Error	0.77	2.59	1.90	1.07	1.21	1.30
No. Reps	8	6	7	24	25	24

Christmas Cactus: Days from visible bud to open flower	Long Day Treatment and Lamp Type					
		Tungsten		Day Extension		
	Short Day Control	DE	NB	FR	DR/W	DR/W/FR
Mean	54.00	50.67	50.14	46.75	46.72	47.17
St Dev	1.93	5.16	3.08	4.39	3.80	6.88
St Error	0.68	1.83	1.16	0.90	0.76	1.40
No. Reps	8	8	7	24	25	24

Chrysanthemum (Tampico White)

Chrysanthemum: Days to visible bud	Long Day Treatment and Lamp Type					
		Tungsten		Day Extension		
	Short Day Control	DE	NB	FR	DR/W	DR/W/FR
Mean	29.50	91.00	91.00	65.67	91.00	91.00
St Dev	3.02	0.00	0.00	3.09	0.00	0.00
St Error	1.07	0.00	0.00	0.62	0.00	0.00
No. Reps	8	8	8	25	25	25

Chrysanthemum: Leaf Number	Long Day Treatment and Lamp Type					
		Tungsten		Day Extension		
	Short Day Control	DE	NB	FR	DR/W	DR/W/FR
Mean	12.00	25.17	22.25	18.20	26.44	21.76
St Dev	1.07	1.94	1.04	2.00	1.23	1.01
St Error	0.38	0.69	0.37	0.40	0.25	0.20
No. Reps	8	8	8	25	25	25

Lisianthus (Florida Silver)

Lisianthus: Days to visible bud	Long Day Treatment and Lamp Type					
		Tungsten		Day Extension		
	Short Day Control	DE	NB	FR	DR/W	DR/W/FR
Mean	156.00	139.00	139.67	137.60	156.00	136.70
St Dev	0.00	0.00	10.97	7.02	0.00	6.50
St Error	0.00	0.00	3.88	1.19	0.00	1.36
No. Reps	8	8	8	35	40	23

Pansy (Majestic Giant Purple)

Pansy: Days to visible bud	Long Day Treatment and Lamp Type					
		Tungsten		Day Extension		
	Short Day Control	DE	NB	FR	DR/W	DR/W/FR
Mean	81.43	37.00	35.63	36.19	78.70	33.48
St Dev	4.28	5.07	3.89	8.10	12.67	6.92
St Error	1.51	1.79	1.38	1.33	2.00	1.09
No. Reps	8	8	8	37	40	40

Pansy: Days from visible bud to open flower	Long Day Treatment and Lamp Type					
		Tungsten		Day Extension		
	Short Day Control	DE	NB	FR	DR/W	DR/W/FR
Mean	19.86	25.25	21.75	32.46	19.48	23.93
St Dev	1.46	10.08	3.41	14.61	2.34	8.21
St Error	0.52	3.56	1.21	2.40	0.37	1.30
No. Reps	8	8	8	37	40	40

Petunia (Express Salmon)

Petunia: Days to visible bud	Long Day Treatment and Lamp Type					
		Tungsten		Day Extension		
	Short Day Control	DE	NB	FR	DR/W	DR/W/FR
Mean	80.13	36.63	45.75	41.05	46.90	37.03
St Dev	3.76	2.33	4.40	3.06	4.66	1.91
St Error	1.33	0.82	1.56	0.48	0.74	0.30
No. Reps	8	8	8	40	40	40

Petunia: Days from visible bud to open flower	Long Day Treatment and Lamp Type					
		Tungsten		Day Extension		
	Short Day Control	DE	NB	FR	DR/W	DR/W/FR
Mean	16.00	17.00	15.50	13.63	14.23	14.13
St Dev	4.21	3.85	3.82	2.34	2.27	1.03
St Error	1.49	1.36	1.35	0.37	0.36	0.16
No. Reps	8	8	8	40	40	40

Poinsettia (Prestige Early Red)

Poinsettia: Days to first red bract	Long Day Treatment and Lamp Type					
	Short Day Control	Tungsten		Day Extension		
		DE	NB	FR	DR/W	DR/W/FR
Mean	37.00	156.00	156.00	87.32	95.13	156.00
St Dev	2.78	0.00	0.00	11.47	12.25	0.00
St Error	0.98	0.00	0.00	2.29	2.55	0.00
No. Reps	8	8	8	25	23	25

Appendix IV: Plant Height Data

Antirrhinum (Bells Red)

Antirrhinum: Plant Height (cm)	Long Day Treatment and Lamp Type														
	Short Day Control	Tungsten		LED Modules - DE					LED Modules - NB				LED Flowering Lamps - DE		
		DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	FR	DR/W	DR/W/FR
Mean	29.75	31.63	33.29	26.63	38.56	31.38	36.00	29.00	32.63	36.25	32.25	33.00	36.36	31.58	31.66
St Dev	2.12	1.30	2.75	1.30	2.53	2.07	1.83	1.91	2.39	3.28	4.92	0.82	2.16	2.23	2.70
St Error	0.75	0.46	1.04	0.46	0.89	0.73	0.65	0.72	0.84	1.16	1.74	0.41	0.35	0.37	0.43
No. Reps	8	8	7	8	8	8	8	7	8	8	8	4	39	36	40

Begonia (Illumination Rose)

Begonia: Plant Height (cm)	Long Day Treatment and Lamp Type													
	100% Blue	Tungsten		LED Modules - DE				LED Modules - NB				LED Flowering Lamps - DE		
		DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	FR	DR/W	DR/W/FR
Mean	11.50	29.38	29.44	23.81	24.29	24.81	23.57	25.13	32.00	24.25	28.75	28.08	26.18	26.25
St Dev	4.95	12.49	6.78	6.10	5.94	9.20	7.41	3.36	12.09	8.40	8.60	9.99	7.79	8.17
St Error	3.50	4.42	2.40	2.16	2.24	3.25	2.80	1.19	4.27	2.97	3.04	2.23	1.74	1.83
No. Reps	2	8	8	8	7	8	7	8	8	8	8	20	20	20

Christmas cactus (Olga)

Christmas cactus: Plant Height (cm)	Long Day Treatment and Lamp Type														
	Short Day Control	Tungsten		LED Modules - DE					LED Modules - NB				LED Flowering Lamps - DE		
		DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	FR	DR/W	DR/W/FR
Mean	15.38	15.50	16.00	14.75	16.25	14.63	15.86	16.38	15.25	16.00	15.63	14.13	15.19	15.64	15.58
St Dev	1.85	1.93	0.82	1.93	1.83	1.77	1.77	1.92	1.16	1.85	2.07	1.73	1.63	1.76	2.06
St Error	0.65	0.68	0.31	0.68	0.65	0.63	0.67	0.68	0.41	0.65	0.73	0.61	0.33	0.35	0.42
No. Reps	8	8	7	8	8	8	7	8	8	8	8	8	24	25	24

Chrysanthemum (Tampico White)

Chrysanthemum: Plant Height (cm)	Long Day Treatment and Lamp Type														
	Short Day Control	Tungsten		LED Modules - DE					LED Modules - NB				LED Flowering Lamps - DE		
		DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	FR	DR/W	DR/W/FR
Mean	27.50	54.88	55.75	39.88	58.71	54.38	62.38	27.71	44.75	53.75	49.00	59.25	53.12	51.20	57.04
St Dev	2.12	4.64	2.31	2.17	3.50	3.02	3.02	1.38	2.82	3.49	1.31	4.37	2.83	2.66	2.92
St Error	0.75	1.64	0.82	0.77	1.24	1.07	1.07	0.49	1.00	1.24	0.46	1.54	0.57	0.53	0.58
No. Reps	8	8	8	8	8	8	8	8	8	8	8	8	25	25	25

Lisianthus (Florida Silver)

Lisianthus: Plant Height (cm)	Long Day Treatment and Lamp Type														
	Short Day Control	Tungsten		LED Modules - DE					LED Modules - NB				LED Flowering Lamps - DE		
		DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	FR	DR/W	DR/W/FR
Mean	19.67	22.75	19.50	13.94	29.00	19.07	29.00	18.19	18.75	25.17	23.17	25.25	29.88	19.88	29.20
St Dev	0.35	2.47	0.87	2.01	0.91	1.18	1.61	1.44	1.36	0.76	0.76	0.35	2.12	2.32	1.27
St Error	0.13	1.75	0.50	0.71	0.46	0.42	0.66	0.51	0.48	0.44	0.44	0.25	0.42	0.46	0.25
No. Reps	7	2	3	8	4	8	6	8	8	3	3	2	25	25	25

Pansy (Majestic Giant Purple)

Pansy: Plant Height (cm)	Long Day Treatment and Lamp Type														
	Short Day Control	Tungsten		LED Modules - DE					LED Modules - NB				LED Flowering Lamps - DE		
		DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	FR	DR/W	DR/W/FR
Mean	14.43	24.94	22.31	14.25	27.69	26.14	31.94	12.50	18.00	20.00	21.06	20.75	22.82	15.90	23.95
St Dev	4.95	5.07	3.47	3.06	5.72	4.30	7.47	2.54	5.81	4.81	5.91	5.39	6.29	2.94	4.43
St Error	1.87	1.79	1.23	1.08	2.02	1.62	2.64	0.90	2.05	1.70	2.09	1.91	1.00	0.46	0.70
No. Reps	7	8	8	8	8	7	8	8	8	8	8	8	40	40	40

Petunia (Express Salmon)

Petunia: Plant Height (cm)	Long Day Treatment and Lamp Type														
	Short Day Control	Tungsten		LED Modules - DE					LED Modules - NB				LED Flowering Lamps - DE		
		DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	FR	DR/W	DR/W/FR
Mean	34.25	42.00	44.88	32.00	49.75	35.13	45.81	34.86	32.13	36.00	37.63	36.88	47.58	33.78	43.65
St Dev	1.16	2.45	4.49	2.65	3.54	4.61	5.02	1.07	4.76	2.83	4.38	2.80	5.18	3.09	2.93
St Error	0.41	0.87	1.59	1.00	1.25	1.63	1.78	0.38	1.68	1.00	1.55	0.99	0.82	0.49	0.46
No. Reps	8	8	8	7	8	8	8	8	8	8	8	8	40	40	40

Poinsettia (Prestige Early Red)

Poinsettia: Plant Height (cm)	Long Day Treatment and Lamp Type														
	Short Day Control	Tungsten		LED Modules - DE					LED Modules - NB				LED Flowering Lamps - DE		
		DE	NB	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	100% Blue	100% Red	100% Far-Red	75% R + 25% FR	25% R + 75% FR	FR	DR/W	DR/W/FR
Mean	13.25	23.31	19.63	19.19	23.56	23.19	28.38	13.81	18.88	26.00	21.56	25.81	24.40	23.20	24.60
St Dev	1.06	2.07	2.17	1.22	4.60	1.75	0.99	1.28	1.75	5.15	1.29	0.96	3.54	1.33	0.98
St Error	0.38	0.73	0.77	0.43	1.63	0.62	0.35	0.45	0.62	1.82	0.46	0.34	0.72	0.28	0.20
No. Reps	8	8	8	8	8	8	8	8	8	8	8	8	24	23	25