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Project leader:	Dr Steve Adams
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GROWER SUMMARY

1.1. Headline

- The project demonstrated how a simple screening protocol could be used to investigate how temperature, daylength and supplementary lighting affect flowering in a range of patio plants.
- Warmer temperatures hastened flowering in all of the patio plant species/cultivars studied, with the exception of Lotus. Long days promoted flowering in 24 out of the 30 cultivars examined, while supplementary lighting hastened flowering in around half of the cultivars tested.

1.2. Background and expected deliverables

Patio plants have become an increasing part of the bedding and pot plant industry for spring and summer sales. They are often vegetatively propagated and ideally the finished product is sold in flower. Many plants use daylength as a signal for floral induction. However, daylength alone is an ambiguous signal in spring and autumn and, hence, some plants use a combination of photoperiod and chilling to ensure that they flower in spring and not in autumn. Furthermore, temperature usually affects flowering time even in species that do not require chilling. There also is evidence to suggest that for a number of species the time to flowering can be hastened by increased light levels.

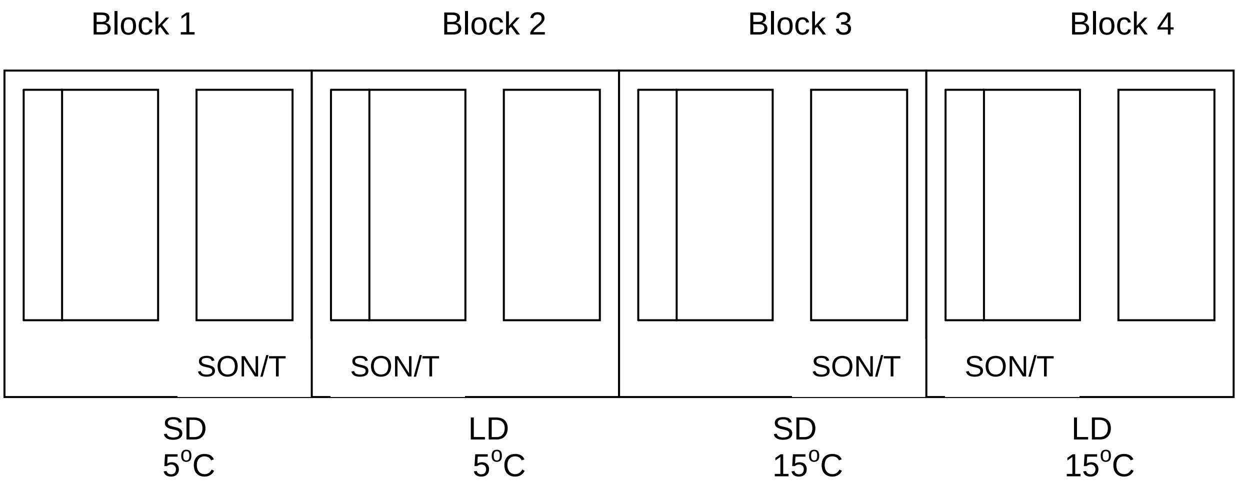
This work set out to demonstrate a screening protocol that could be used by growers on their own nurseries to quantify the way in which different species/cultivars respond to their environment, as well as providing valuable information on the responses of 30 different cultivars (14 species). The trial was designed to address the following questions:

- Does temperature influence the speed of flowering?
- Do plants develop flowers faster under long/short days?
- Is flowering improved by the use of supplementary lighting?

1.3. Summary of the project and main conclusions

Patio plants (30 cultivars of 14 different species; Table 1) were obtained as rooted cuttings from commercial propagators. Plants arrived from week 2 to week 5 of 2004. Cuttings were potted up into 9cm pots on arrival at Warwick HRI and placed into a range of different environmental treatments within 4 different glasshouse compartments/blocks.

<u>Experimental Plan</u>



Plants were inspected three times a week so that dates of visible bud appearance and flower opening could be recorded for each plant. The plant height, or in the case of trailing species the length of the longest shoot, was recorded for each plant when 50% of the plants of a given treatment had flowered.

Temperature

Plants were grown in four identical glasshouse compartments each 41m^2. Two compartments were set to provide a heating temperature of 5^{o}C, and the other two were set to 15^{o}C. Vent temperatures were set to 3°C above these heating set-points. The 15°C compartments initially ran slightly above this set-point and temperatures were fairly stable, while the 5°C compartment fluctuated more with changes in ambient temperature. The difference between the 5 and 15°C compartments diminished over the course of the experiment as the ambient temperatures increased over time.

Warmer temperatures hastened flowering in 13 out of the 14 species examined (29 out of the 30 cultivars examined) (Table 2). Low temperatures only promoted flowering in Lotus. In nearly all of the cultivars studied warmer temperatures hastened both the appearance of visible buds (Table 1) and the rate of flower development. Therefore, warmer temperatures could be used to hasten flowering of a wide range of patio plants. In most plants this also increased plant growth, although for some may have resulted in a slight loss of compactness. Growth regulators were not used in this trial, and may be used to elevate this problem.

Daylength

At each temperature, one compartment initially provided natural short days (SD), although the daylength increased over the course of the experiment. The other compartment received day-extension lighting (LD) provided by tungsten bulbs (~1.7 µmol/m^2/s at bench height (~ 100 lux)) so as to give a minimum daylength of 15 hours (lit from sunset to 23:00 h (GMT)), although this also increased over the course of the experiment due to an earlier sunrise. To avoid problems associated with light pollution in the SD compartments, blackout screens were used on the walls of each compartment from sunset until sunrise.

Most of the species/cultivars were shown to be long day plants (Tables 1 and 2). The only plant in which flowering was hastened by short days was Lotus, while Argyranthemum, Bidens, Diascia, Felicia, and Verbena ‘Red Knight’ showed no significant response to daylength. The response to long day lighting was very pronounced in some species. For example, flowering was hastened by up to 40 days in Petunia (Surfinia). Therefore, there is considerable potential to use day extension or night break lighting to promote flowering, although crops grown slightly later in the year, when daylengths are increasing, may benefit less from this treatment. The fact that very few patio plants are short day plants means that lighting could be used on a combination of species to hasten flowering and make flowering time more predictable. The effect of daylength was often on reducing the time to visible bud; flower development was generally less sensitive to daylength. Therefore, long day lighting would not need to be applied over the whole life of the crop and could be applied for only a limited duration.

A detrimental effect of long day lighting was increased stem elongation (Table 3). If tungsten lamps were used commercially this might result in increased use of growth regulators. However, the increased stem elongation was most likely a result of the red:far-red ratio of the tungsten lamps and not a response to long days *per see*. Therefore, it would be worth considering the use of other lamp types, for example, compact fluorescent lamps which have a different spectral output.

Light integral (supplementary lighting)

Within each compartment, half of the plants received supplementary lighting, which was provided by two 400W SON/T lamps per compartment. At plant height supplementary light levels were on average 41µmol/m^2/s (~3000 lux). SON/T lamps were baffled so that the unlit treatment in the same compartment was unaffected. The supplementary lighting was on for 8 hours per day from 08:00 - 16:00 h (GMT). Natural light levels increased over the course of the experiment and so supplementary lighting gave a proportionally larger effect early in the year when the quantity of natural light was low.

Figure 1. *Photograph showing the layout of plants and lamps.*

The response to supplementary lighting tended to be less pronounced compared with the effects of temperature and daylength. Supplementary lighting hastened flowering in around half of cultivars studied (Table 2). However, the maximum response was one week. Therefore, the potential for manipulation of flowering through supplementary lighting is limited unless they are used to create long days. The benefits would be greater for early crops. However, the costs of applying supplementary lighting are much greater than the use of low intensity long day lighting using compact fluorescent or tungsten bulbs. Although supplementary lighting may have an added benefit of increasing plant quality as a result of enhanced growth.

Table 1. *The effect of temperature, daylength and supplementary lighting on reducing the number of days to visible bud of a range of patio plants. For example, Antirrhinum 'Deep Purple' had visible buds 28 day sooner in the 15°C set-point compartments when compared with the 5°C compartments.*

Cultivar	**Reduction in the time to visible bud (days)**					
	Temperature		**Daylength**		**Light integral**	
	5°C	**15°C**	**SD**	**LD**	**-SON/T**	**+SON/T**
Antirrhinum Lum. Deep Purple		28		13[1]		5
Antirrhinum Lum. Harvest Red		22		10		
Argyranthemum Sultans Dream		9				5
Bacopa Snowflake						
Bidens aurea		7				
Diascia Joyce's Choice		25				7
Felicia Blue						4
Fuchsia Alice Hoffmann		37[3]		17[1]		
Fuchsia Barbara Windsor		25[3]		20[1]		3
Fuchsia Betty		13		10[1,5]		3
Fuchsia Dark Eyes		32		30[1,5]		
Fuchsia Deep Purple		29		24[5]		
Fuchsia Gene		25		12		3
Fuchsia Liza		27		24[5]		
Fuchsia Lyle's Unique		15[5]		19[5]		3
Fuchsia Marcia		22		5		
Fuchsia Maybe Baby		13		13[1,5]		
Fuchsia Nice 'n' Easy		28[3]		12[1]		5
Fuchsia Patio Princess		21		15		4[6]
Fuchsia Pink Marshmallow		24[3]		21[1]		
Fuchsia Pink Spangles		29[3]		20[1]		2
Lobelia Richardii		9[3]		27[1]		
Lobelia White Star		16		22		
Lotus Bertholetii	See text		See text			See text
Nemesia Blue Lagoon		9				6
Petunia Surfinia Blue		27[3]		46[1]		
Sanvitalia Aztec Gold		35[4]		14[2]		
Scaevola Brilliant		19		>10		7
Verbena New Ophelia		19		10		3
Verbena Red Knight		8				8

[1] Difference reduced if temperature reduced
[2] Difference reduced if temperature increased
[3] Difference reduced if SD
[4] Difference reduced if LD
[5] Difference reduced if pinched
[6] Difference reduced if in larger plug

Table 2. *The effect of temperature, daylength and supplementary lighting on reducing the number of days to flower opening of a range of patio plants. For example, Antirrhinum 'Deep Purple' had open flowers 30 day sooner in the 15°C set-point compartments when compared with the 5°C compartments.*

Cultivar	Reduction in the time to open flowers (days)					
	Temperature		Daylength		Light integral	
	5°C	15°C	SD	LD	-SON/T	+SON/T
Antirrhinum Lum. Deep Purple		30		13[1]		4
Antirrhinum Lum. Harvest Red		27		8		
Argyranthemum Sultans Dream		16				
Bacopa Snowflake		27		4		4
Bidens aurea		18				
Diascia Joyce's Choice		28				6
Felicia Blue		10				5
Fuchsia Alice Hoffmann		38[3]		16[1]		
Fuchsia Barbara Windsor		29[3]		21[1]		4
Fuchsia Betty		20		11[1,5]		
Fuchsia Dark Eyes		37		29[1,5]		
Fuchsia Deep Purple		30		18[5]		
Fuchsia Gene		31		11		4
Fuchsia Liza		33		25[5]		3
Fuchsia Lyle's Unique		20[5]		15[5]		3
Fuchsia Marcia		29				
Fuchsia Maybe Baby		22[5]		12[1,5]		
Fuchsia Nice 'n' Easy		33[3]		12[1]		5
Fuchsia Patio Princess		30[6]		12[1]		
Fuchsia Pink Marshmallow		23		21[1]		
Fuchsia Pink Spangles		31[3]		21[1]		2
Lobelia Richardii		27[3]		28[1]		
Lobelia White Star		26[3]		20[1]		2
Lotus Bertholetii	See text		See text			See text
Nemesia Blue Lagoon		22		2		6
Petunia Surfinia Blue		36[3]		40[1]		
Sanvitalia Aztec Gold		38[4]		12[2]		3
Scaevola Brilliant		44[3]		14[1]		5
Verbena New Ophelia		28		13		
Verbena Red Knight		8				7

[1] Difference reduced if temperature reduced
[2] Difference reduced if temperature increased
[5] Difference reduced if pinched
[4] Difference reduced if LD
[3] Difference reduced if SD
[6] Difference reduced if in larger plug

Table 3. *The effect of temperature, daylength and supplementary lighting on increasing the height/length of the longest shoot (in cm) at marketing of a range of patio plants. For example, Antirrhinum 'Deep Purple' plants were 5cm taller at marketing in the 5°C compartments when compared with the 15°C compartments.*

Cultivar	Increase in plant height/shoot length (cm)					
	Temperature		Daylength		Light integral	
	5°C	15°C	SD	LD	-SON/T	+SON/T
Antirrhinum Lum. Deep Purple	5			4		
Antirrhinum Lum. Harvest Red	3					
Argyranthemum Sultans Dream						
Bacopa Snowflake				3		2
Bidens aurea		14		6		8
Diascia Joyce's Choice						7[1]
Felicia Blue		5		6		
Fuchsia Alice Hoffmann				5		
Fuchsia Barbara Windsor		10		7		
Fuchsia Betty				6[2]		
Fuchsia Dark Eyes		3		3		
Fuchsia Deep Purple		9[2]				5
Fuchsia Gene		2				
Fuchsia Liza						
Fuchsia Lyle's Unique		11		3		
Fuchsia Marcia	2			4		
Fuchsia Maybe Baby		8		5		
Fuchsia Nice 'n' Easy		4		5		
Fuchsia Patio Princess		3		2		
Fuchsia Pink Marshmallow		5	6			
Fuchsia Pink Spangles		3		4		
Lobelia Richardii		9				
Lobelia White Star						
Lotus Bertholetii		20		13		
Nemesia Blue Lagoon		7		4		3
Petunia Surfinia Blue		18		5		
Sanvitalia Aztec Gold		5				
Scaevola Brilliant	6			6		
Verbena New Ophelia		8		3		
Verbena Red Knight		11		9	2	

[1] Difference reduced if temperature reduced
[2] Difference reduced if pinched

1.4. Financial benefits

The financial benefits of earlier flowering are difficult to quantify. If product currently sold without flower and can be brought into flower for marketing, then there may be an increase in the value of the product. Whilst for most patio and basket plants the advantage of hastening of flowering will be a reduction in cropping time. However, reductions in cropping times will only be of financial value if the space that is freed up can be utilised for an additional crop, or if the same throughput is achieved from a smaller production area.

The cost of lighting has been calculated using a range of electricity tariffs, based on the set up and treatments used in the trial at Wellesbourne (Table 4). These calculations are based on one 400W SON/T lamp every 10 m^2 drawing 435W electrical power for 8 hours per day, or one tungsten lamp (100W) every 4.5 m^2 for on average 6 hours per day to extend the daylength. Some caution is needed when scaling up these figures for commercial houses as the lighting can probably be applied more efficiently over larger areas. Installation and maintenance costs would also need to be considered.

The duration and hence cost of LD lighting could be reduced if night-break lighting were used instead of day-extension lighting. Costs could also be reduced by using compact fluorescent lamps and/or lowering the lamps so that they are nearer to the height of the bench, although it would be important to ensure the light levels were still reasonably even across the crop. The cost of lighting with one compact fluorescent (25W) every 4.5 m^2 for 2 hours per day is shown for comparison.

Table 4. *The cost of lighting with tungsten, SON/T and compact fluorescent lamps based on a range of different electricity tariffs. See text for details.*

Electricity tariff (pence per kWh)	Cost of lighting (pence/m^2/week)		
	Tungsten	SON/T	Compact Fluorescent
2.5	2.33	6.09	0.19
3.0	2.80	7.31	0.23
3.5	3.27	8.53	0.27
4.0	3.73	9.74	0.31
4.5	4.20	10.96	0.35
5.0	4.67	12.18	0.39

The costs of raising the temperature will depend on the weather conditions and the environmental strategy that is chosen. Raising the heating set-points would have fuel cost implications. An alternative and more cost effective solution would be to increase vent temperatures to maximise solar gain. However, this may result in increased humidity and so care should be taken to monitor humidity and introduce humidity control strategies.

1.5. Action points for growers

- A screening protocol along the lines described in this report could be used commercially to quantify flowering responses and improve crop scheduling.
- Consider using night-break lighting to promote flowering in a range of patio plants.
- Long day lighting with tungsten lamps caused stretching in a number of species; however, this can probably be overcome through the use of compact fluorescent lamps.
- Warmer temperatures hastened flowering in nearly all of the patio plants studied. Higher vent temperatures could be used as a cost effective means of raising the average temperature, providing sufficient emphasis is placed on humidity control.
- Supplementary lighting only hastened flowering in half of the cultivars examined, and so has limited potential to improve crop scheduling unless used to extend the length of the day.
- Lotus had a different response to all of the other species investigated. Lotus requires low temperatures and short days to flower and so ideally should be grown according to a different production protocol.

SCIENCE SECTION

2.1. Introduction

Patio plants have become an increasing part of the bedding and pot plant industry for spring and summer sales. They are often vegetatively propagated and ideally the finished product is sold in flower. These plants are estimated to have a farm gate value of £50M (DEFRA statistics 2001/02).

Many plants use daylength as a signal for floral induction. Unlike temperature or light level, the daylength for a particular latitude on any given day of the year is always the same, so this can be used by plants as an indicator of the time of year, even during unseasonal weather conditions. Plants are categorised as either short day plants (SDP), long day plants (LDP) or day neutral plants (DNP). LDP and SDP can then be subdivided into obligate (qualitative), where a particular photoperiod is essential for flowering, or facultative (quantitative), where a particular photoperiod can hasten flowering but is not essential (Thomas and Vince-Prue, 1997).

However, daylength alone is an ambiguous signal in spring and autumn and, hence, some plants use a combination of photoperiod and chilling (vernalisation) to ensure that they flower in spring and not in autumn. Furthermore, temperature usually affects flowering time even in species that do not require chilling; as is the case with many biological processes, the rate of progress to flowering is affected by temperature. The effect of temperature on the timing of developmental events such as flowering can usually be attributed to mean diurnal temperature rather than distinct day/night effects. There also is evidence to suggest that for a number of species the time to flowering can be hastened by increased light levels.

This work sets out to demonstrate a screening protocol that could be used by growers on their own nurseries to quantify the way in which different species/cultivars respond to their environment, as well as providing valuable information on the responses of 30 different cultivars (14 species). The trial was designed to address the following questions:

- Does temperature influence the speed of flowering?
- Do plants develop flowers faster under long/short days?
- Is flowering improved by the use of supplementary lighting?

2.2. Materials and methods

Plants were grown in four identical glasshouse compartments (E1, E2, E3 and E4) each 41m^2. Two compartments were set to provide a heating temperature of 5^{o}C, and the other two were set to 15^{o}C. Vent temperatures were set to 3°C above these heating set-points. At each temperature, one compartment initially provided natural short days (SD) and the other received day-extension lighting (LD) provided by tungsten bulbs (~1.7 µmol/m^2/s at bench height (~ 100 lux)) so as to give a minimum daylength of 15 hours (lit from sunset to 23:00 h (GMT)). To avoid problems associated with light pollution in the SD compartments, blackout screens were used on the walls of each compartment from sunset until sunrise.

Figure 1. *Photographs showing the linear array of experimental glasshouse compartments and the internal layout of plants and lamps.*

Within each compartment, half of the plants received supplementary lighting, which was provided by two 400W SON/T lamps per compartment. At plant height supplementary light levels were on average 41µmol/m^2/s (~3000 lux). SON/T lamps were baffled so that the unlit treatment in the same compartment was unaffected. The supplementary lighting was on for 8 hours per day from 08:00 - 16:00 h (GMT).

Plants (30 cultivars of 14 different species) were obtained as rooted cuttings from commercial propagators. Plants arrived from week 2 to week 5. Cuttings were potted up into 9cm pots containing Levington M2 compost on arrival at Warwick HRI. Plants were watered for the first two to three weeks, they were then initially fed with Vitafeed 111 and subsequently Vitafeed 102 (0.67g/l) was used for the bulk of the experiment.

Twenty plants were grown in each treatment; 10 in a block in the north half of the compartment and 10 in the south half. The blocks of plants were placed in the same relative positions in each compartment. The only exceptions were Fuchsias, Petunia and Diascia, where only 10 plants were grown per treatment.

Some species were already pinched before they arrived at Warwick HRI, others were pinched after potting up. Some of the Fuchsias and Lotus were pinched a second time to maintain more compact plants. In these cases half of the plants were pinched (as would have been done commercially) and half were left unpinched as so not to remove potential flower buds and affect flowering times.

Plants were treated for P&D problems as required. Some of the Fuchsias arrived with *Botrytis cinerea* which spread within the compartments in particular to other Fuchsias and Antirrhinums. Consequently, plants were sprayed with Bavistin (0.5 g/l) for three consecutive weeks. This was followed by one application of Bravo 500 (4 ml/l), and one application of Scala (2ml/l) which caused some leaf scorch to a few species (in particular Lobelia and Sanvitalia). As fungicides that would leave spray deposits were undesirable, Rovral WP (1g/l) was subsequently used in a regular spray programme for the control of *Botrytis*. Some aphids were observed on the Fuchsias in one compartment towards the end of the experiment, these were sprayed with Pyrethrin. Biological control agents were used for the control of sciarid fly (plants were drenched with nematodes *Steinernema feltiae*) and thrips (*Amblyseius cucumeris* were introduced).

Environmental data was recorded via the climate computer (DGT-Volmatic; LCC 1200 Super 4 climate computer) and a number of independent sensors. This included using thermistor sensors (10kΩ Fenwall thermistors) inserted into the aspirated screens and four light sensors (quantum sensors; Skye Instruments Ltd) were also positioned in the compartments just above the crop. These sensors were connected to a data-logger (DL2, Delta-T Devices Ltd) set to scan every 60 seconds and record every 10 minutes.

Plants were inspected three times a week so that dates of visible bud appearance and flower opening could be recorded for each plant. Visible bud was defined for each species (Appendix 2) and flowering was taken to be the time when the first flower of each plant opened. The plant height, or in the case of trailing species the length of the longest shoot, was recorded for each plant when 50% of the plants of a given treatment had flowered. All of the flowering and bud appearance times are expressed as the number of days from potting up, which is when the treatments started.

2.3. Results and discussion

The DGT and independent sensors showed good agreement with regards to the air temperatures. When small deviations were observed the sensors were checked and recalibrated. Furthermore, the compartments that had the same set-points had similar temperature regimes (Figure 2). The 15°C compartments initially ran slightly above this set-point and temperatures were fairly stable, while the 5°C compartment fluctuated more with changes in ambient temperature. The difference between the 5 and 15°C compartments diminished over the course of the experiment as the ambient temperatures increased over time.

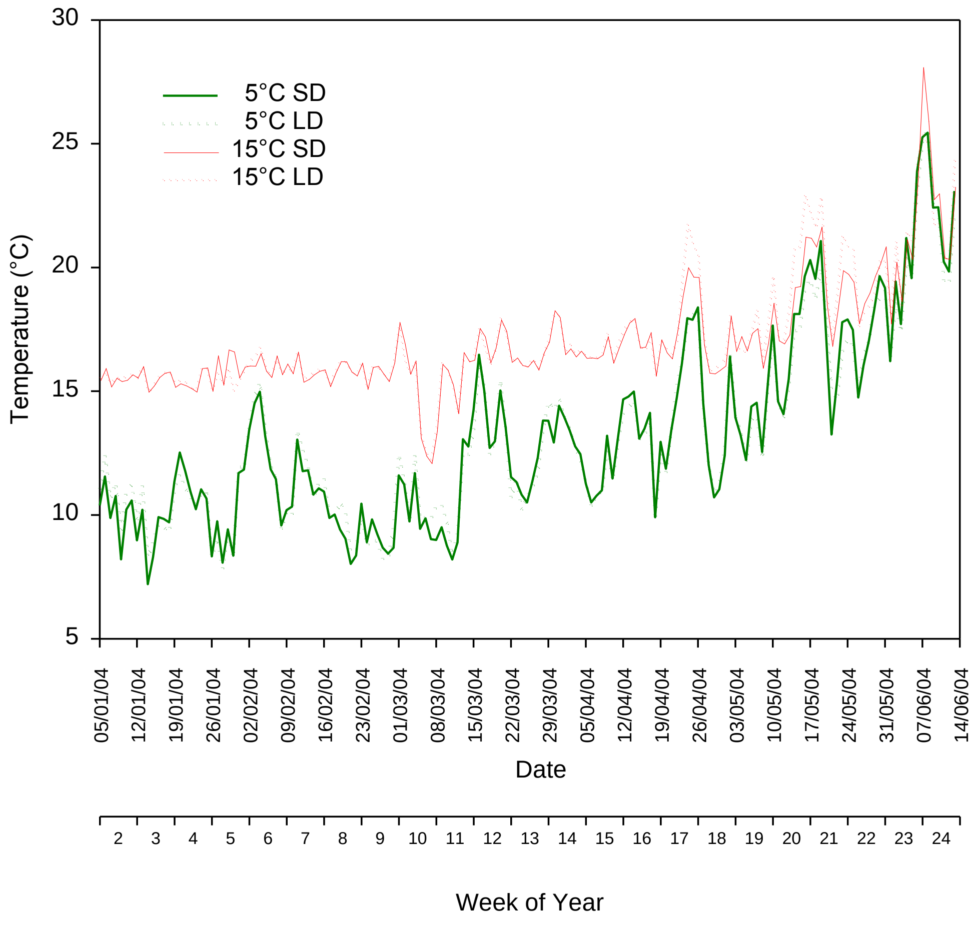


Figure 2. *Air temperatures (24hr averages) recorded for the four glasshouse compartment over the course of the experiment.*

Light levels increased over the course of the experiment (Figure 3). The supplementary lighting gave a fixed quantity of light which had a proportionally larger effect early in the year when the quantity of natural light was low. The natural daylength also increased over time (Figure 4). Lighting from sunset to 23:00 h (GMT) with tungsten lamps gave a minimum daylength of 15 h, although this also increased over the course of the experiment due to an earlier sunrise.

The plants results are presented by species and cultivar listed in alphabetical order.

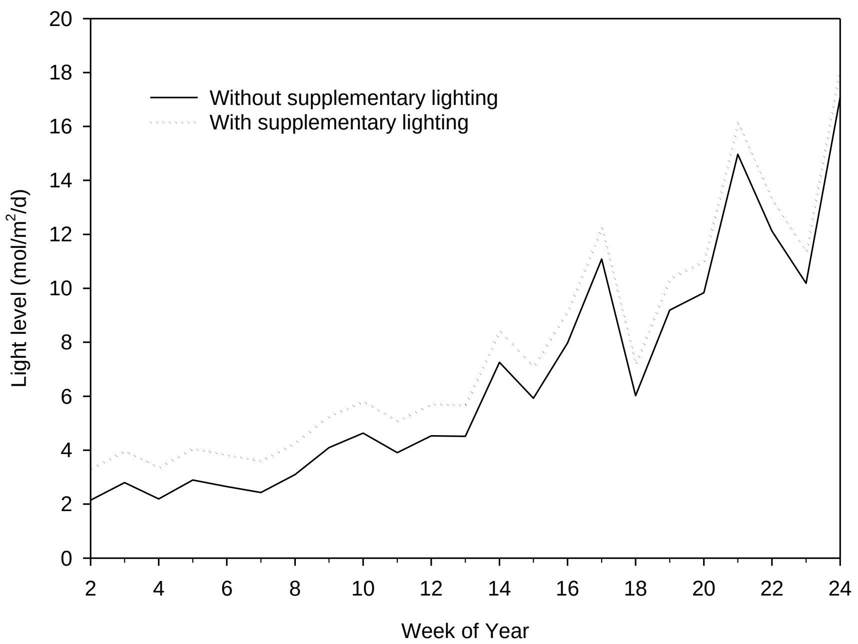


***Figure 3**. Light levels (PPFD) recorded in the glasshouse compartments over the course of the experiment. The increase due to supplementary lighting is shown.*

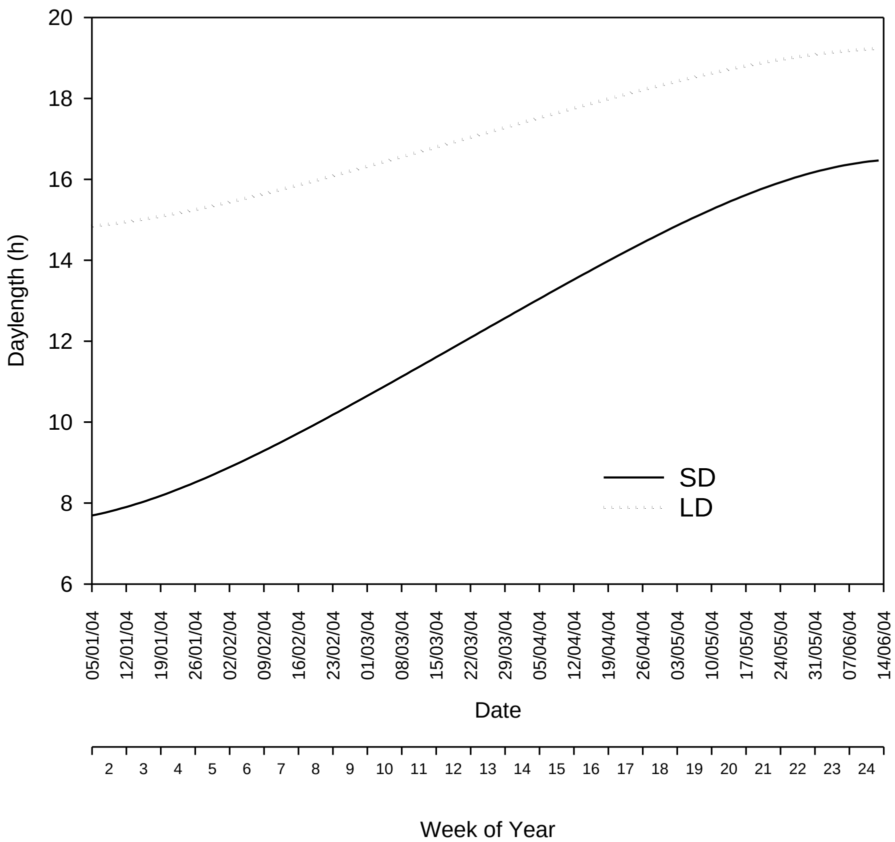


***Figure 4**. The change in natural daylength (SD) over the course of the experiment. The effect of lighting from sunset to 23:00 h (GMT) can also be seen (LD).*

Antirrhinum cv. Luminaire™ Deep Purple

(Antirrhinum majus L.)

Many cultivars of antirrhinum (Snapdragons) are quantitative long day plants; they will flower in short days but flower earlier in long days (Cockshull, 1985), flowering also tends to be hastened at higher temperature regimes (Maginnes and Langhans, 1961; Creamer *et al*., 1998). However, little published information is available on the Luminaire™ line of training Snapdragons.

Rooted cuttings were potted up on the 21 January and then pinched on 27 January. The time of bud appearance was hastened by warm temperatures, long daylengths and the use supplementary lighting. Buds appeared 28 days earlier in the 15°C compartments compared with the 5°C compartments. Supplementary lighting hastened bud appearance by 5 days. Long days also hastened bud appearance, this effect was more pronounced in the warm compartments. Long days hastened flowering by 4 days at 5°C compared with 13 days at 15°C.

The rate of flower development was only significantly affected by the temperature regime; the time from bud appearance to flower opening was 2 days quicker in the 15°C compartments. As a result flowers opened 30 days earlier in the warm compartments.

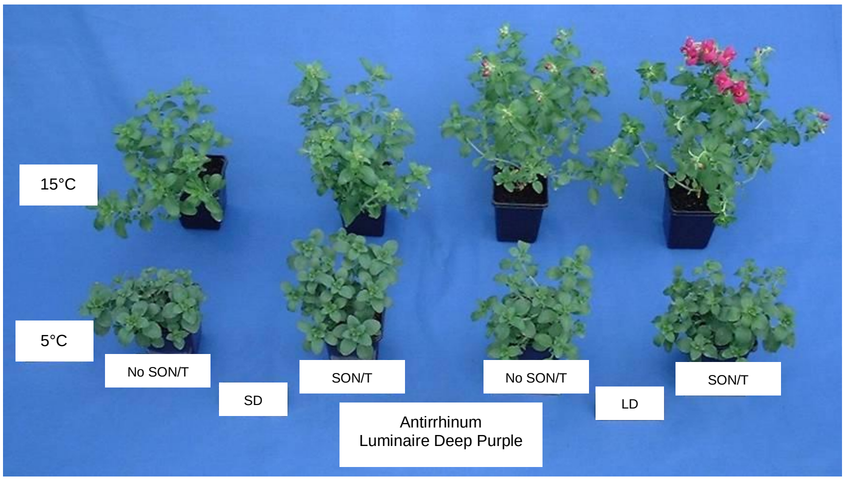


Figure 5. *The effect of temperature, daylength and supplementary lighting on Antirrhinum cv. Luminaire™ Deep Purple. Photograph taken on 13/04/04.*

Plants grown at a set-point of 15°C were on average 5cm shorter at flowering when compared to the plants grown at a set-point of 5°C (which flowered much later); 26 compared with 31 cm. Long day lighting with tungsten bulbs also increased the plant height by around 4cm.

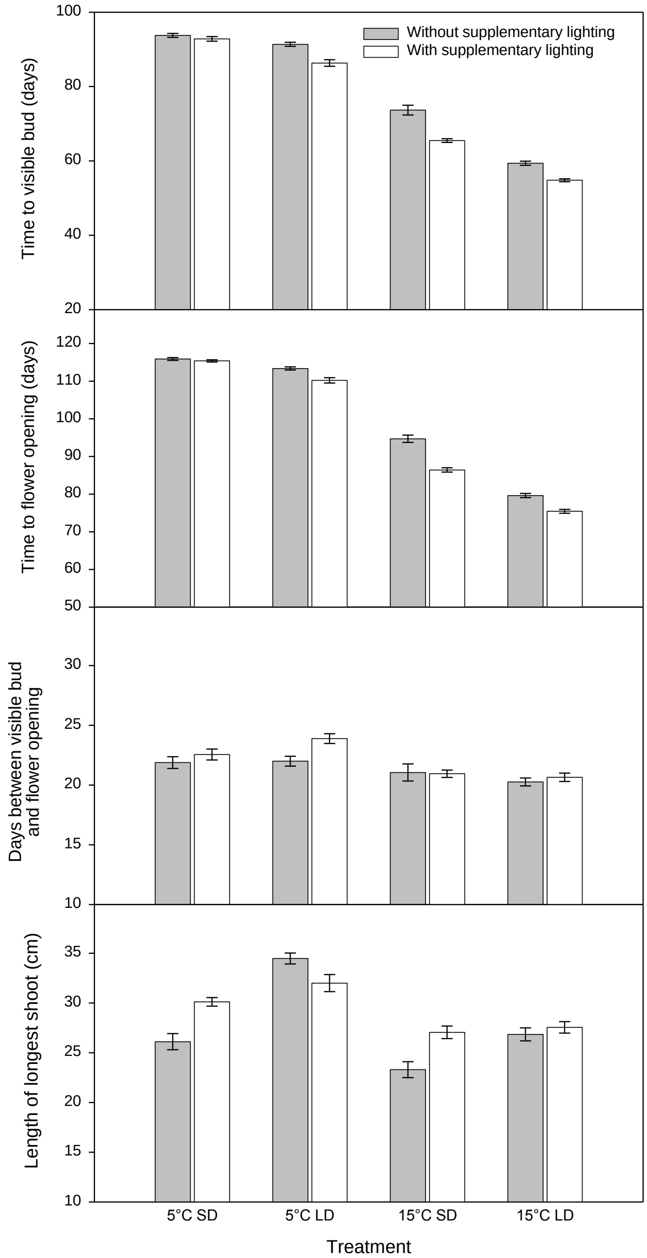


Figure 6. *The effect of temperature, daylength and supplementary lighting on Antirrhinum cv. Luminaire^{TM} Deep Purple*

Antirrhinum cv. Luminaire^{TM} Harvest Red

(Antirrhinum majus)

As with Deep Purple rooted cuttings were potted up on the 21 January and then pinched on 27 January although on average flowered 26 days earlier. The time of bud appearance was hastened by warm temperatures and long daylengths. Buds appeared 22 days earlier in the 15°C compartments compared with the 5°C compartments. Long days hastened bud appearance by 10 days.

The rate of flower development was only significantly affected by the temperature regime; the time from bud appearance to flower opening was 5 days quicker in the 15°C compartments. As a result flowers opened 27 days earlier in the warm compartments.

Plants grown at a set-point of 15°C were on average 3cm shorter at flowering when compared to the plants grown at a set-point of 5°C (which flowered much later). However, neither long days nor supplementary lighting had a significant effect on plant height at flowering.

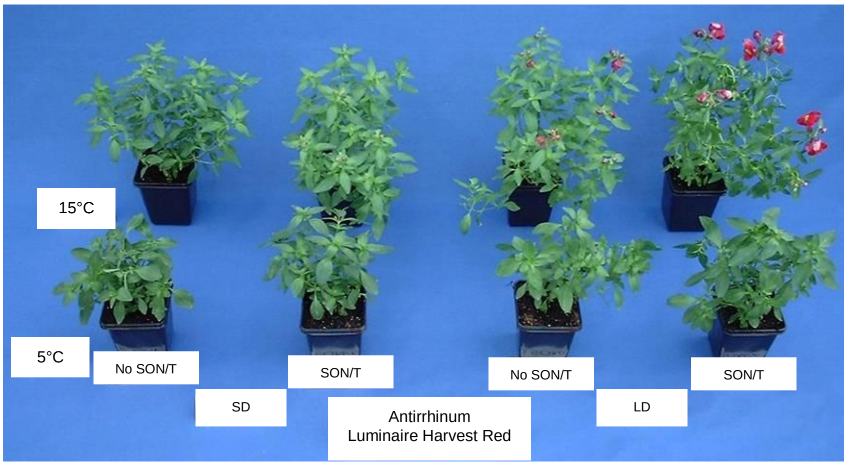


Figure 7*. The effect of temperature, daylength and supplementary lighting on Antirrhinum cv. Luminaire^{TM} Harvest Red. Photograph taken on 19/03/04.*

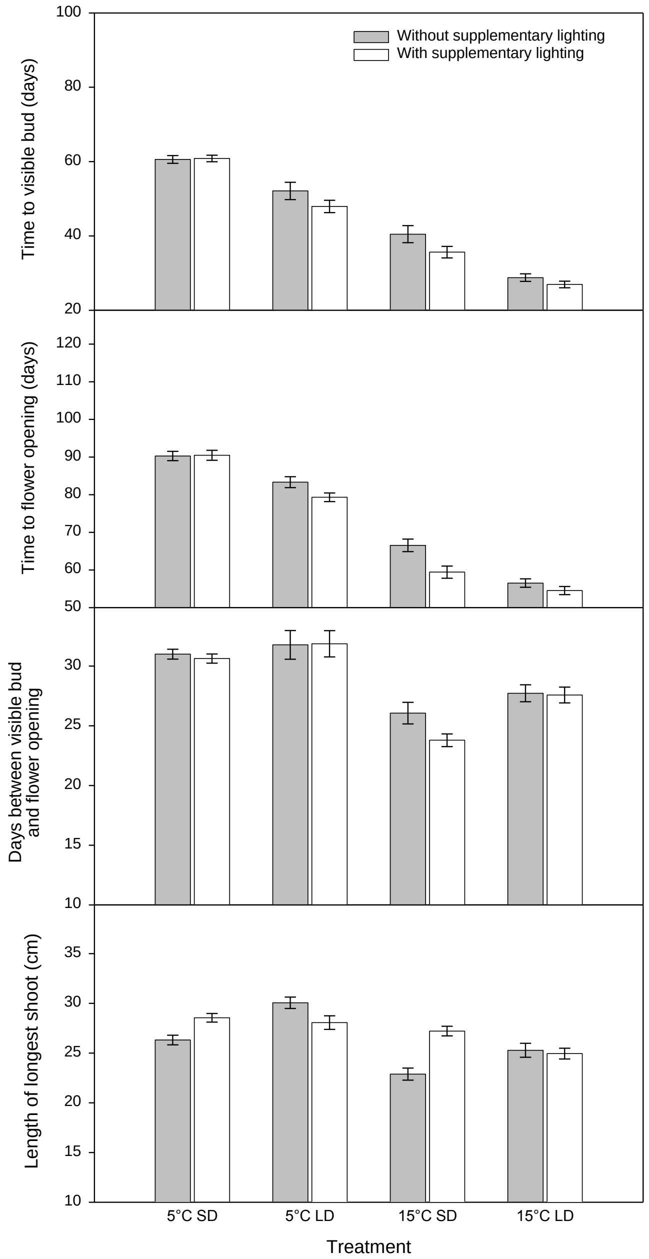


Figure 8. *The effect of temperature, daylength and supplementary lighting on Antirrhinum cv. Luminaire^{TM} Harvest Red*

Argyranthemum cv. Sultans Dream

(Argyranthemum frutescens)

Argyranthemum (Marguerite Daisy) are short lived perennials which originate from the Canary Islands. There would appear to be little published information about the effects of environment on flowering, although according to Hamrick (2003) Marguerites are long day plants.

Rooted cuttings were potted up on 20 January and then pinched on 26 January. The time of bud appearance was hastened by warm temperatures. Buds appeared 9 days earlier in the 15°C compartments compared with the 5°C compartments. Supplementary lighting hastened bud appearance by on average 5 days.

The rate of flower development was only significantly affected by the temperature regime; the time from bud appearance to flower opening was 6 days less in the 15°C compartments. As a result flowers opened 16 days earlier in the warm compartments.

Plants were on average 31cm tall (to the flower) at marketing. However, none of the treatments had a significant effect on the plant height.

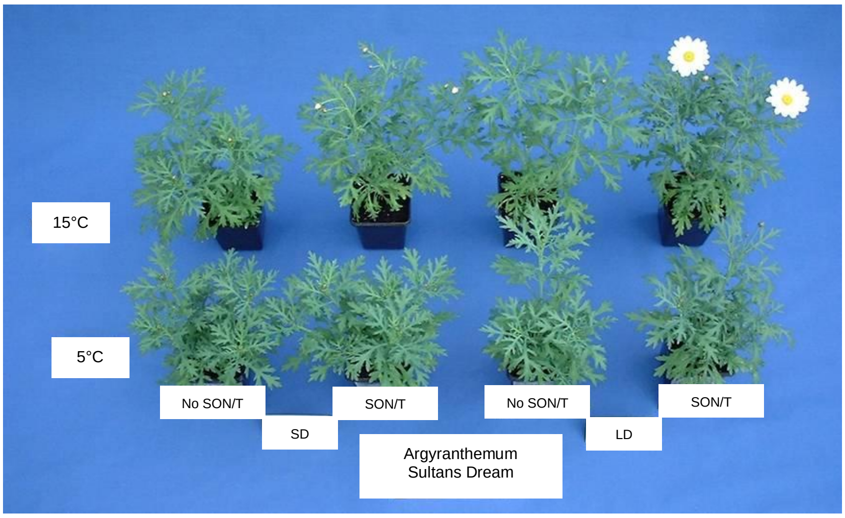


***Figure 9**. The effect of temperature, daylength and supplementary lighting on Argyranthemum cv. Sultans Dream. Photograph taken on 01/04/04.*

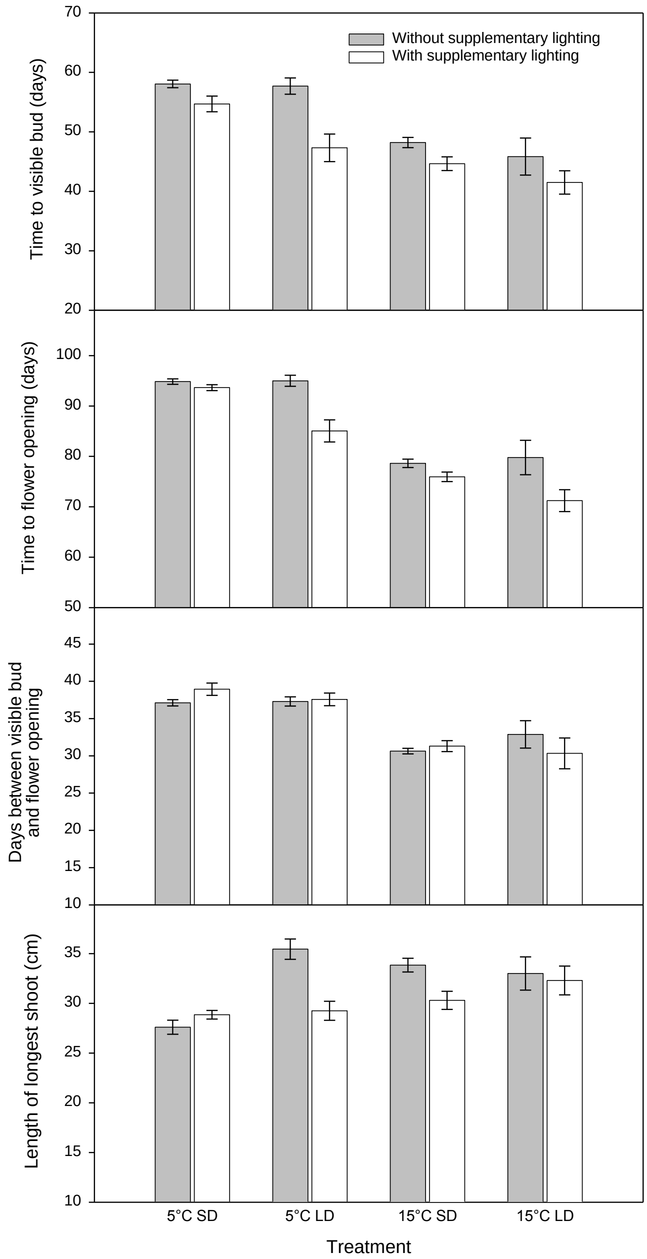


Figure 10. *The effect of temperature, daylength and supplementary lighting on Argyranthemum cv. Sultans Dream*

Bacopa cv. Snowflake

(Sutera cordata)

According to Hamrick (2003), Bacopa are day neutral, although flowering is intensified at higher light levels and temperatures below 18°C. Rooted cuttings, which arrived pinched, were potted up on 7 January. Most of the plants already had buds and so the time of visible bud could not be recorded. A few of the plants also had open flowers on arrival; however, these flowers soon dropped and so were ignored.

Temperature had the biggest effect on flowering time. Increasing the temperature set-point from 5 to 15°C hastened flowering by 27 days. Long day and supplementary lighting also had a significant, although much smaller effect. Both hastened flowering by 4 days.

Temperature did not affect the length of the longest shoot at flowering. However, lighting with either tungsten or supplementary lamps increased the shoot length. Long days increased the average length from 17 to 20 cm, while supplementary lighting increased the mean shoot length by just over 2 cm.

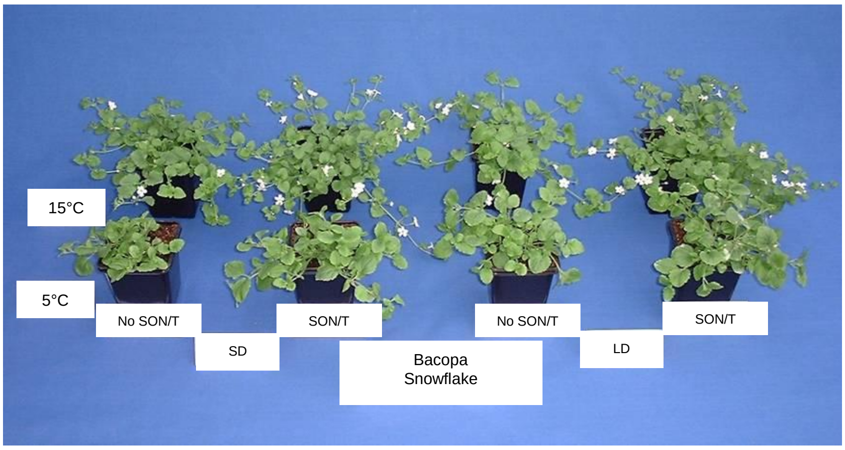


***Figure 11**. The effect of temperature, daylength and supplementary lighting on Bacopa cv. Snowflake. Photograph taken on 04/03/04.*

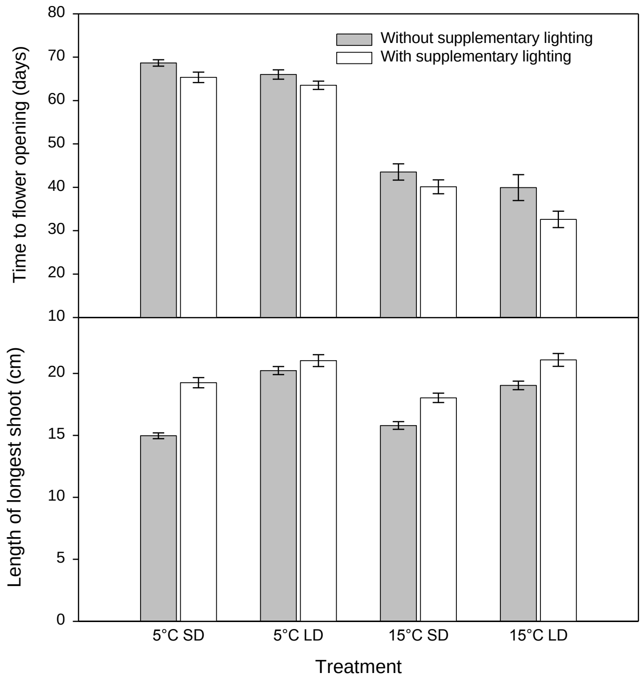


Figure 12. *The effect of temperature, daylength and supplementary lighting on Bacopa cv. Snowflake*

Bidens

(Bidens aurea)

Bidens are an herbaceous perennial that is native to the Southern United States. Rooted cuttings were potted up and put into the different treatments on 22 January.

The time of bud appearance was hastened by warm temperatures; buds appeared 7 days earlier in the 15°C compartments compared with in the 5°C compartments. Warmer temperatures also hastened the flower development by around 11 days and as a result these plants flowered on average 18 days earlier. The lighting treatments did not have a significant effect on the time of bud appearance or flower opening.

The length of the longest shoot was affected by all of the treatments. Shoot length was 35 cm in the 15°C compartments, compared with 21 cm in the 5°C compartments. Lighting with tungsten and supplementary lamps increased shoot length by 6 cm and 8 cm, respectively.

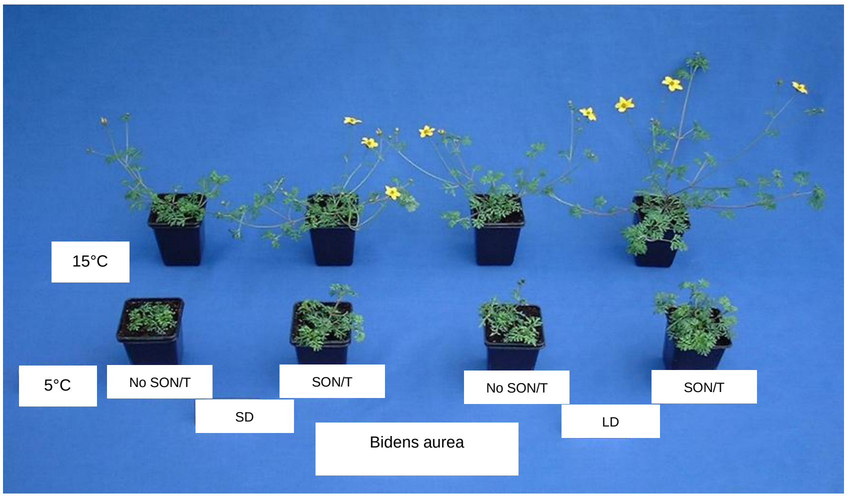


***Figure 13**. The effect of temperature, daylength and supplementary lighting on Bidens. Photograph taken on 12/03/04.*

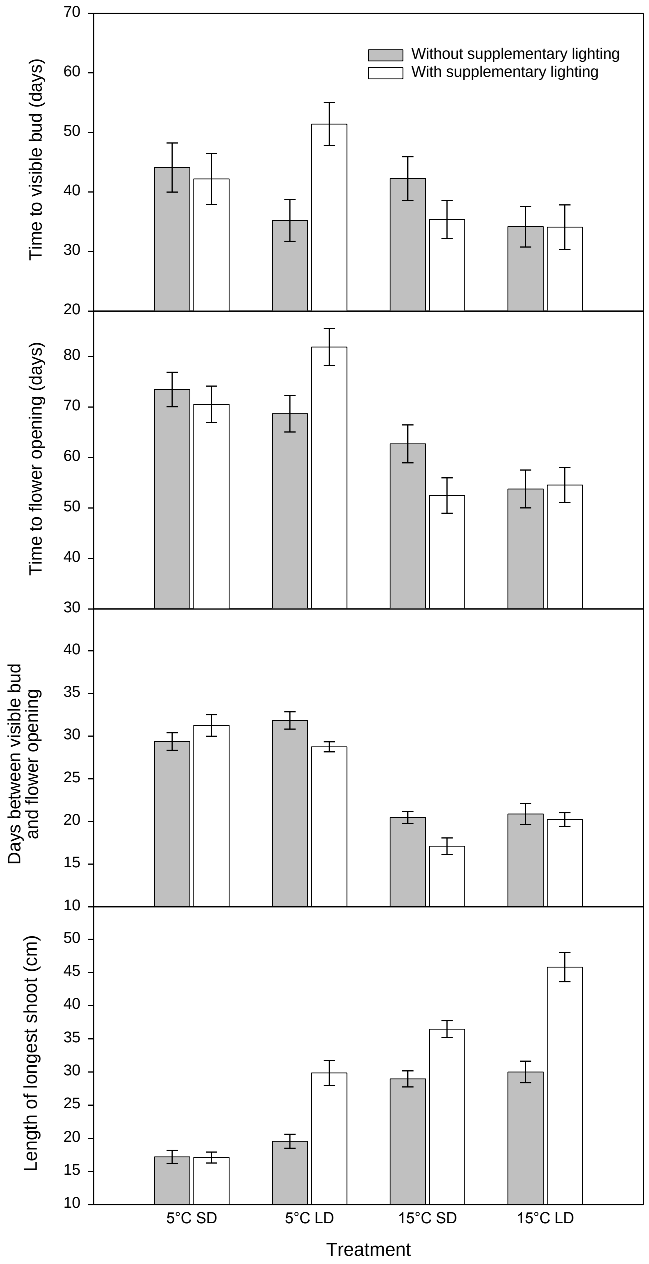


Figure 14. *The effect of temperature, daylength and supplementary lighting on Bidens aurea.*

Diascia cv. Joyce's Choice

(Diascia)

Diascia are insensitive to daylength, although flowering is promoted by higher light levels (Hamrick, 2003). Rooted cuttings of Diascia were potted up on 22 January. These plants had been pinched prior to delivery. Warm temperatures and supplementary lighting hastened bud appearance. Buds were visible 25 days earlier in the 15°C compartments compared with the low temperature compartments. Supplementary lighting hastened bud appearance on average by 7 days.

The effects on the time from bud appearance to flower opening were less pronounced, although again temperature had a significant effect (4 days). The overall effect was that plants grown at a set-point of 15°C flowered after 78 days compared with 106 days in the low temperature regime.

The only treatment to have a significant effect on the length of the longest shoot was supplementary lighting. This interacted with temperature such that the difference between lit and unlit plants was greater (those lit with supplementary lights were 7cm longer) in the 15°C compartments.

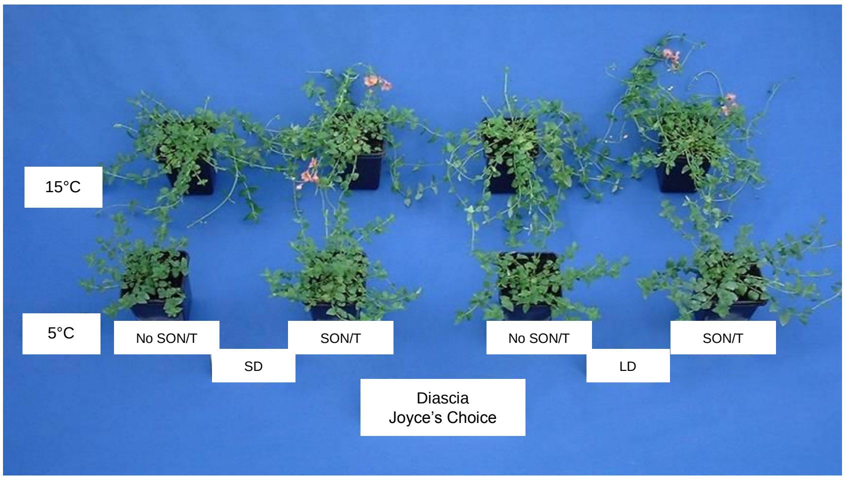


***Figure 15**. The effect of temperature, daylength and supplementary lighting on Diascia cv. Joyce's Choice. Photograph taken on 13/04/04.*

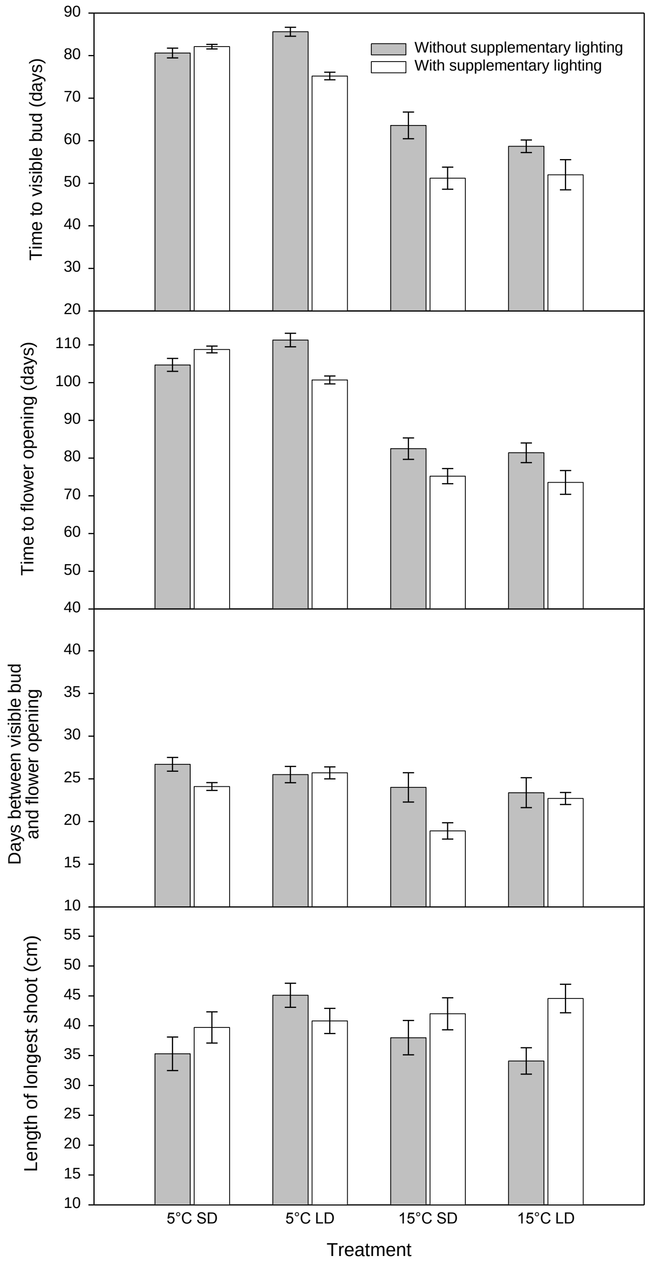


Figure 16. *The effect of temperature, daylength and supplementary lighting on Diascia cv. Joyce's Choice.*

Felicia cv. Blue

(Felicia amelloides)

Blue Felicia (Blue Marguerite) is an evergreen perennial that originates from Southern Africa. Rooted cuttings were potted up on 22 January and were then pinched on 6 February.

The only treatment to significantly affect the time of bud appearance was supplementary lighting; this hastened bud appearance by 4 days. However, temperature affected the subsequent flower development. The time from bud appearance to flowering was hastened by 7 days in the warm compartments. Overall the first flowers opened after 101 days in the 15°C compartments compared with 111 days at 5°C.

The length of the longest shoot was increased by both long day lighting and warm temperatures. Long days increased shoot length by 6 cm, while increasing the temperature increased the length by 5 cm.

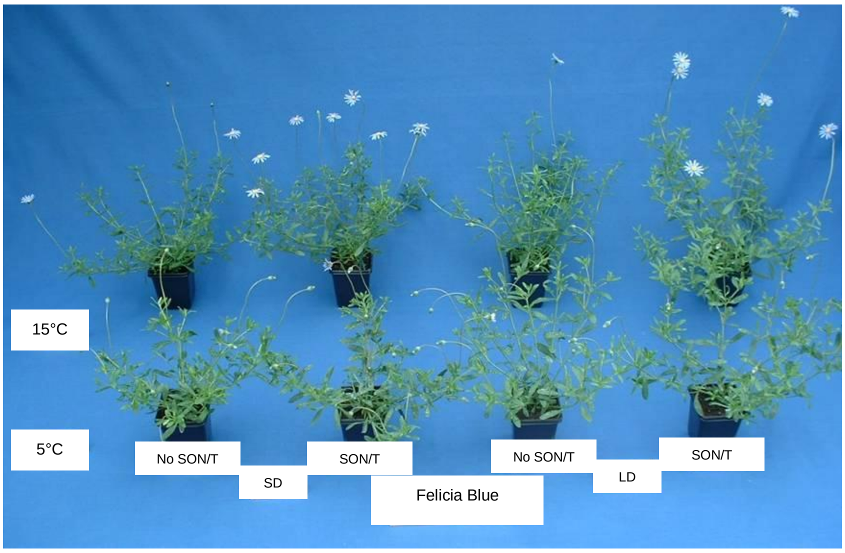


***Figure 15**. The effect of temperature, daylength and supplementary lighting on Blue Felicia. Photograph taken on 10/05/04.*

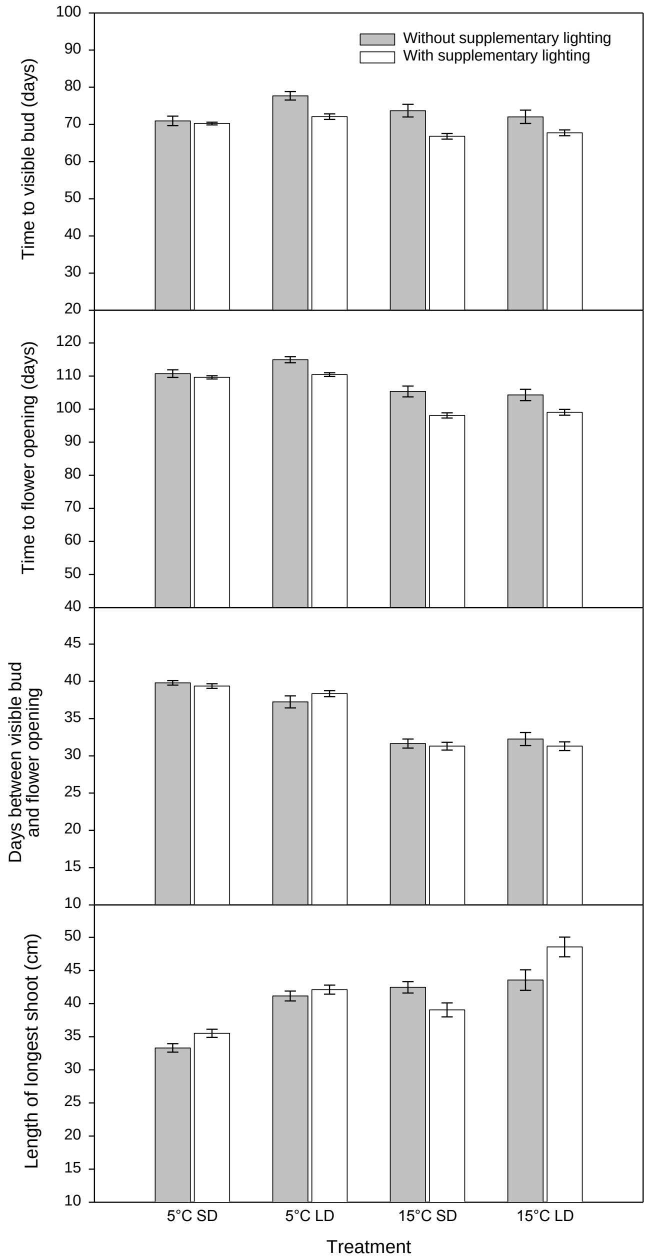


Figure 16. *The effect of temperature, daylength and supplementary lighting on Blue Felicia.*

Fuchsia cv. Alice Hoffman

(Fuchsia x hybrida)

The genus *Fuchsia* is comprised of some 100 species of woody shrubs which are native to Mexico, Patagonia, New Zealand and Tahiti. While some cultivars are day neutral, most cultivars are long day plants; some have an obligate response while others have a quantitative response (Wilkins, 1985). Flower development tends to occur independent of daylength once flowers have initiated. Temperature has a greater effect on flower development than on flower initiation (Wilkins, 1985).

Rooted cuttings of Alice Hoffman were potted up on 22 January and then pinched on 3 February. Buds were visible on average after 92 days although this duration was significantly affected by temperature and daylength. These two factors interacted such that plants were more responsive to long days in the warm compartments. Long day lighting hastened bud appearance by 4 days in the 5°C compartments compared with 17 days in the 15°C compartments. Increasing the temperature set-point hastened bud appearance by 37 days under long days and 25 days in the natural daylength compartments.

***Figure 17**. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Alice Hoffman. Photograph taken on 10/05/04.*

Treatments had little effect on the time from bud appearance to flower opening. However, due to their effects on time of bud appearance flower opening was affected by both temperature and daylength. Plants grown at a set-point of 5°C under a natural daylength flowered after 140 days, compared with 98 days with a 15°C set-point and long days.

Plant height was increased as a result of long day lighting, this increased height by on average 5 cm. This effect was greater in the 5°C compartments.

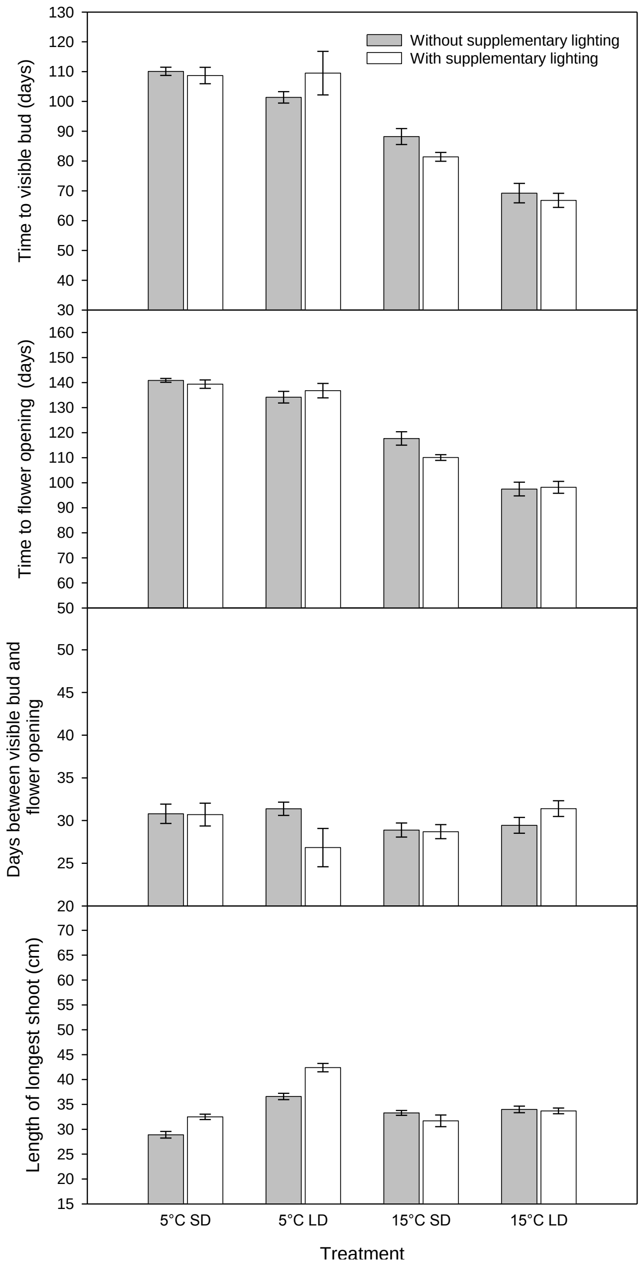


Figure 18. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Alice Hoffmann.*

Fuchsia cv. Barbara Windsor

(Fuchsia x hybrida)

Rooted cuttings of Barbara Windsor were potted up on 22 January and then pinched on 3 February. Buds were visible on average after 102 days, although this duration was significantly affected by temperature and daylength. Again these two factors interacted such that plants were more responsive to long days in the warm compartments. Long day lighting hastened bud appearance by 7 days in the 5°C compartments compared with 20 days in the 15°C compartments. Increasing the temperature set-point hastened bud appearance by 12 days under a natural daylength compared with 25 days under long days. In this cultivar supplementary lighting also hastened bud appearance, although only by 3 days.

Warmer temperatures hastened bud development by on average 2 days. The combined effects were such that long days combined with a warmer temperature regime hastened flower opening by 33 days compared with the low temperature natural daylength regime. Supplementary lighting hastened flowering by a further 4 days.

Increasing the temperature regime tended to increase growth and increased plant height by 10 cm. Long day lighting with tungsten lamps increased plant height by 7 cm.

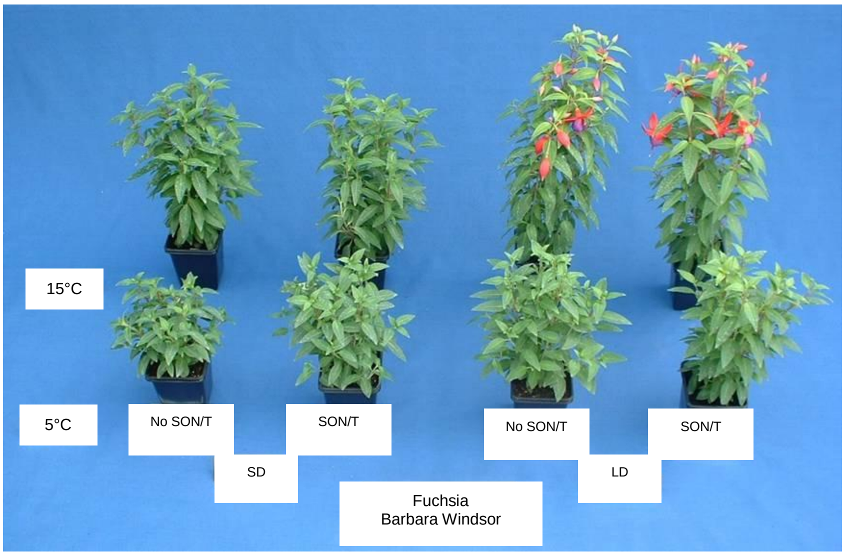


***Figure 19**. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Barbara Windsor. Photograph taken on 10/05/04.*

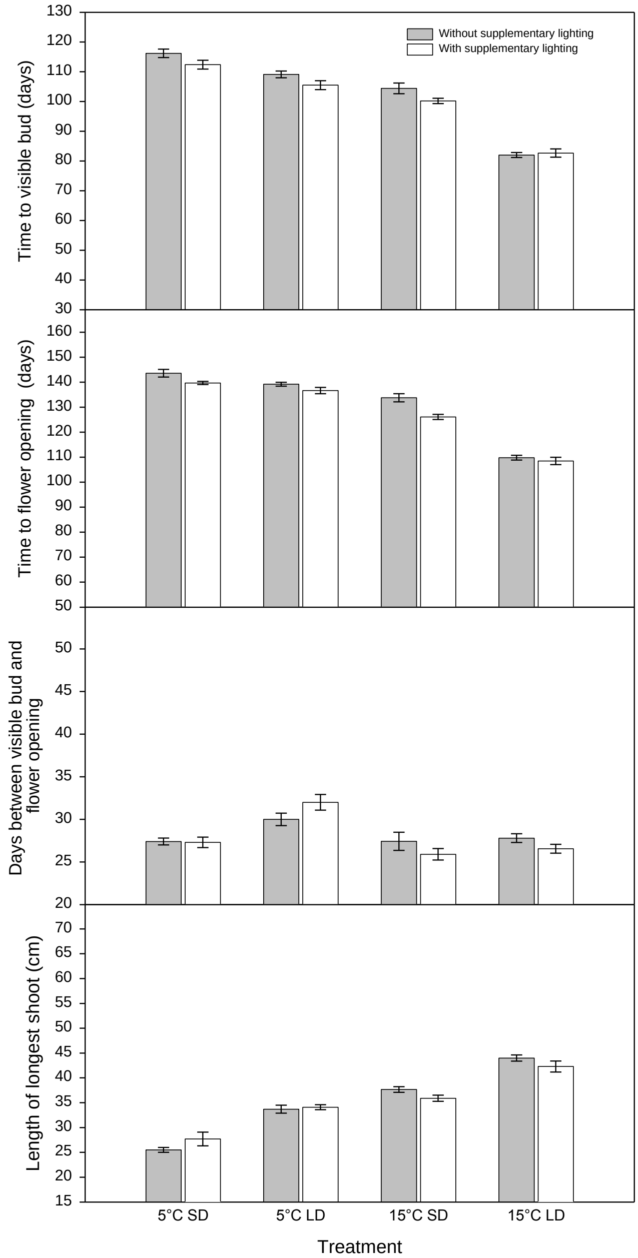


Figure 20. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Barbara Windsor.*

Fuchsia cv. Betty

(Fuchsia x hybrida)

Rooted cuttings of Betty were potted up on 2 February. These had been pinched prior to delivery, although half of the plants were pinched again on 4 March. Pinching delayed bud appearance by 6 days. Buds appeared on average 13 days earlier in the warm compartments and 4 days sooner under long days. The response to daylength was, however, greater in the warmer compartments and on plants that were not re-pinched. In some treatments long days hastened bud appearance by 10 days. Supplementary lighting also had a significant effect, this hastened bud appearance by 3 days.

The only treatment to have a marked effect on the rate of flower development was temperature. Increasing the temperature set-point shortened the period from visible bud to open flower by 7 days. On average plants flowered after 92 days. Overall warmer temperatures hastened flower opening by 20 days. Long day lighting hastened flowering by 4 days on average, although as already discussed the effect of long day lighting was greater (up to 11 days) in some treatments. Supplementary lighting had a smaller effect.

***Figure 21**. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Betty. Photograph taken on 28/04/04.*

Pinching reduced the height at flower opening by 2 cm, while increasing the temperature increased height by just over 1 cm. The treatment having the greatest impact on height (6 cm) was long day lighting. The effect of long day lighting was reduced when plants were pinched.

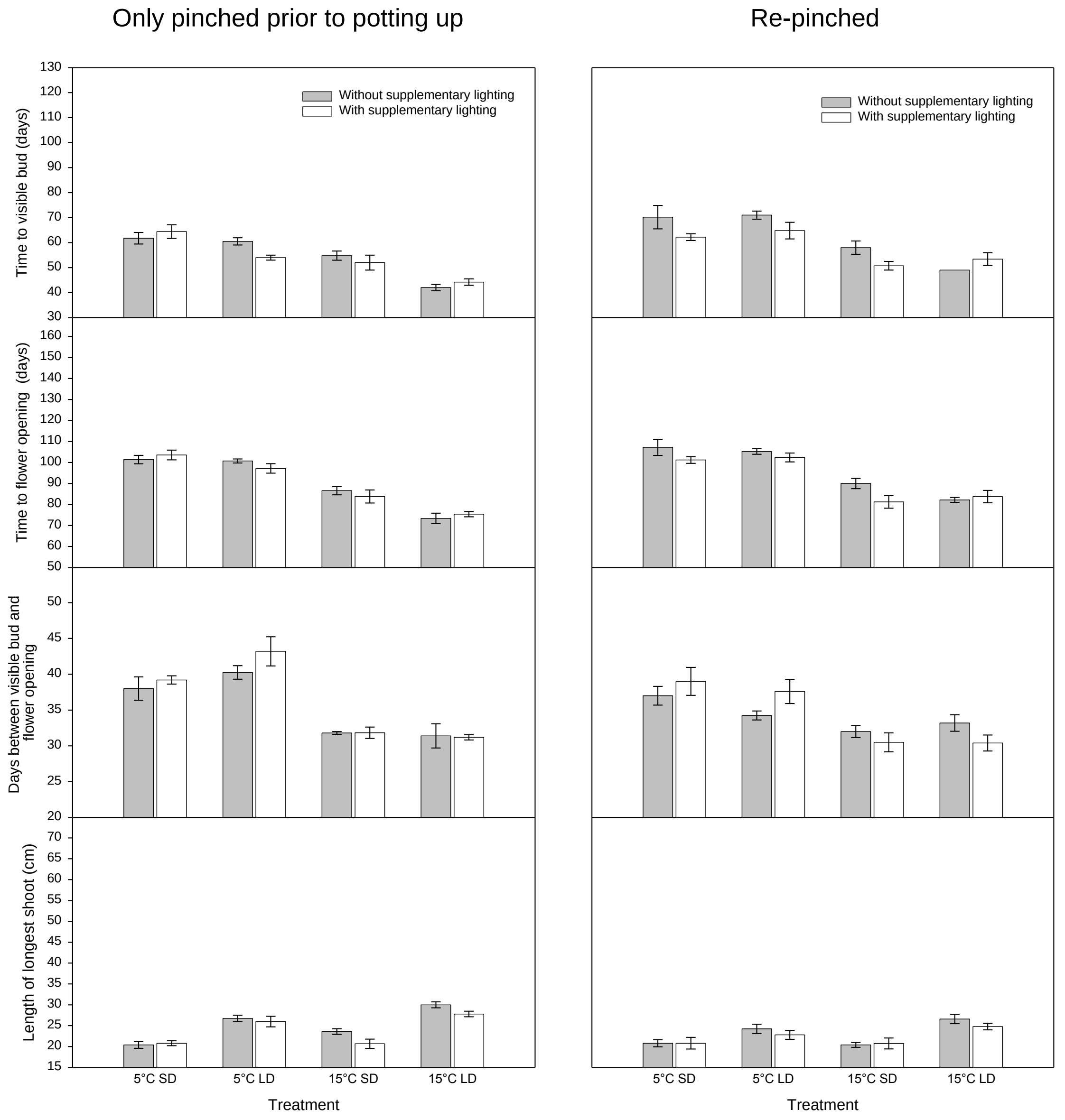


Figure 22. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Betty.*

Fuchsia cv. Dark Eyes

(Fuchsia x hybrida)

Rooted cuttings of Dark Eyes were potted up on 2 February. These had been pinched prior to delivery, although half of the plants were pinched again on 4 March. The second pinching delayed bud appearance by 14 days. Buds appeared on average 32 days earlier in the warm compartments and 18 days sooner under long days. The response to daylength was again greater in the warmer compartments and on plants that were not re-pinched. In some treatments long days hastened bud appearance by 30 days. Supplementary lighting did not have a significant effect.

Temperatures affected bud development; this phase was hastened by 4 days in the warm compartments. Overall plants flowered 37 days sooner when grown at a set-point of 15°C compared with 5°C. The overall effect of daylength was similar to that described for bud appearance. Plants that were not re-pinched and grown at 15°C under long days flowered after 73 days, compared with 133 days at 5°C with a natural daylength.

Pinching reduced the length of the longest shoot at flowering by 3 cm, whereas increasing the temperature increase the shoot length by 3 cm. Long day lighting had a similar effect; this also increased the shoot length by 3cm.

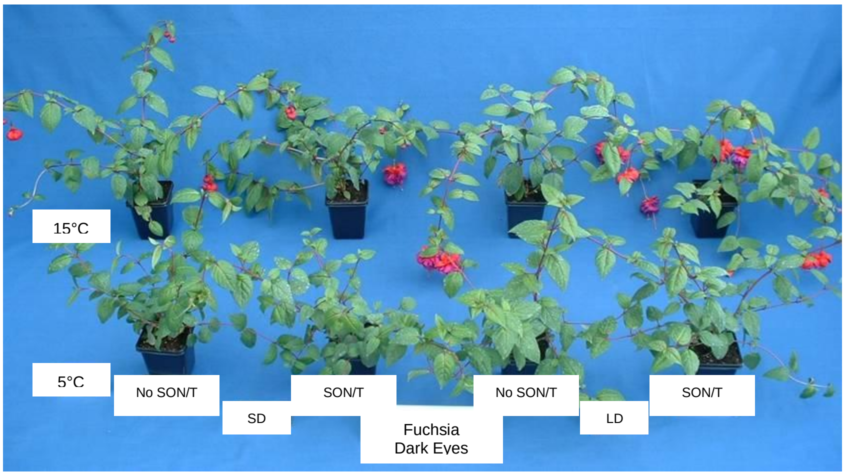


***Figure 23**. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Dark Eyes. Photograph taken on 10/05/04.*

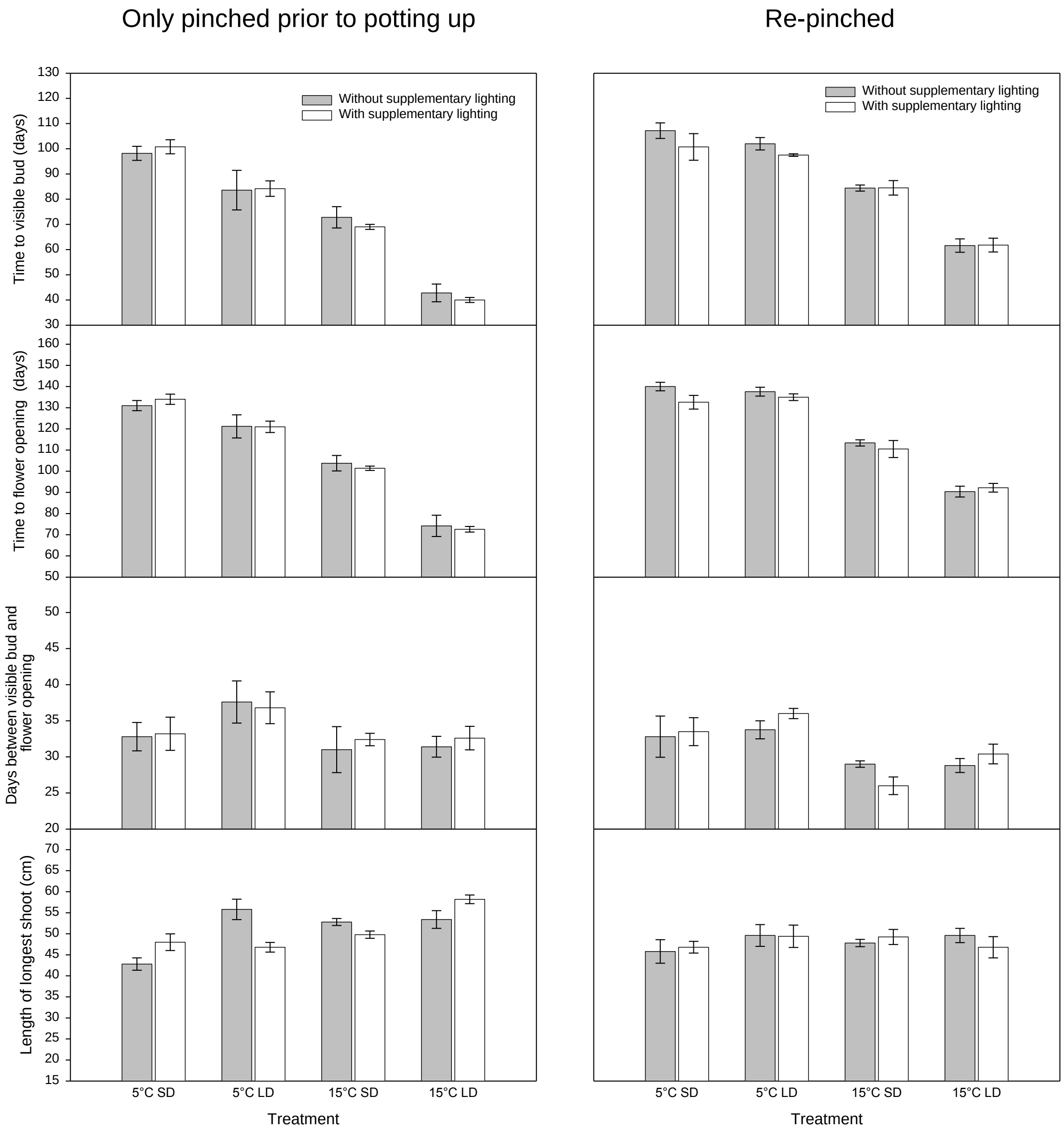


Figure 24. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Dark Eyes*

Fuchsia cv. Deep Purple

(Fuchsia x hybrida)

Rooted cuttings of Deep Purple were potted up on 22 January. These had been pinched prior to delivery, although half of the plants were pinched again on 3 March. Pinching delayed bud appearance by 20 days. Buds appeared on average 29 days earlier in the warm compartments. Plants only responded to long days when they were not pinched a second time; long days hastened bud appearance by 24 days. Plants that were re-pinched showed little response to daylength. Supplementary lighting did not have a significant effect on the time of bud appearance.

None of the treatments had a consistent effect on the time from visible bud to flower opening and so the overall effects of the treatments on the time to flowering was similar to that for bud appearance.

Supplementary lighting increased shoot length by 5 cm. Plants that were not pinched a second time had shoots that were 9 cm longer in the warm compared with cool compartments.

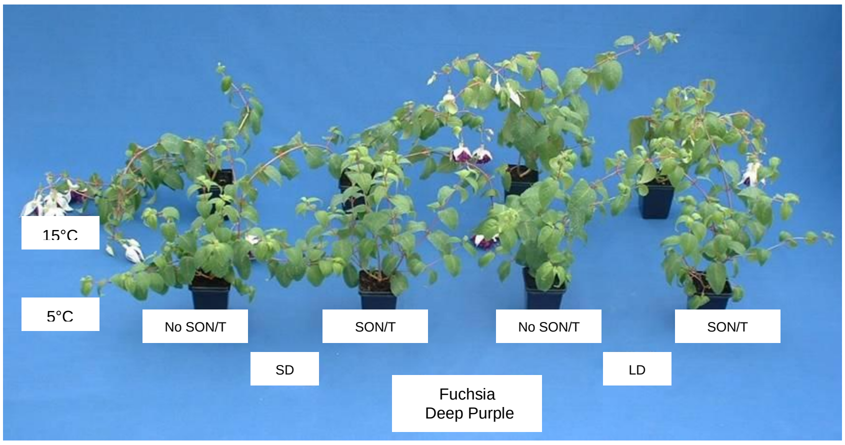


***Figure 25**. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Deep Purple. Photograph taken on 25/05/04.*

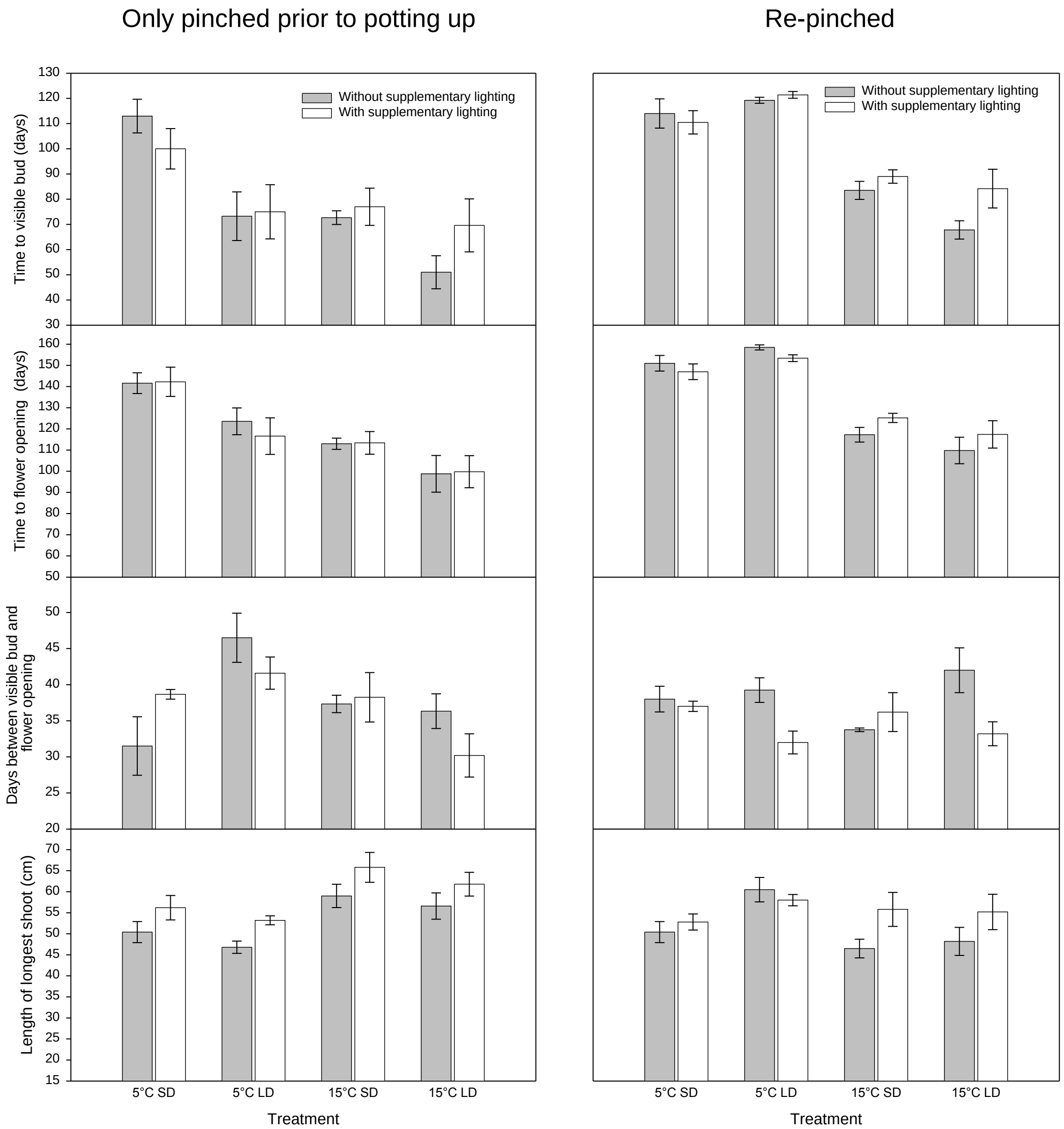


Figure 26. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Deep Purple*

Fuchsia cv. Gene

(Fuchsia x hybrida)

Rooted cuttings of Deep Purple were potted up on 2 February. These had been pinched prior to delivery, although half of the plants were pinched again on 4 March. Pinching delayed bud appearance by 5 days. Buds appeared on average 25 days earlier in the warmer compartments, 12 days earlier under long days, and 3 days earlier as a result of supplementary lighting.

The time from bud appearance to flower opening was hastened slightly in the warmer compartments. Overall plants flowered after an average of 111 days in the cool compartments compared with 80 days in the warmer compartments. Daylength and supplementary lighting did not have a significant effect on the rate of flower development, and so the differences in overall time to flower were similar to those described for bud appearance.

The effects of the treatments on the length of the longest shoot was minimal, although plants grown in the warm compartments tended to have shoots 2 cm longer compared with those in the cooler compartments.

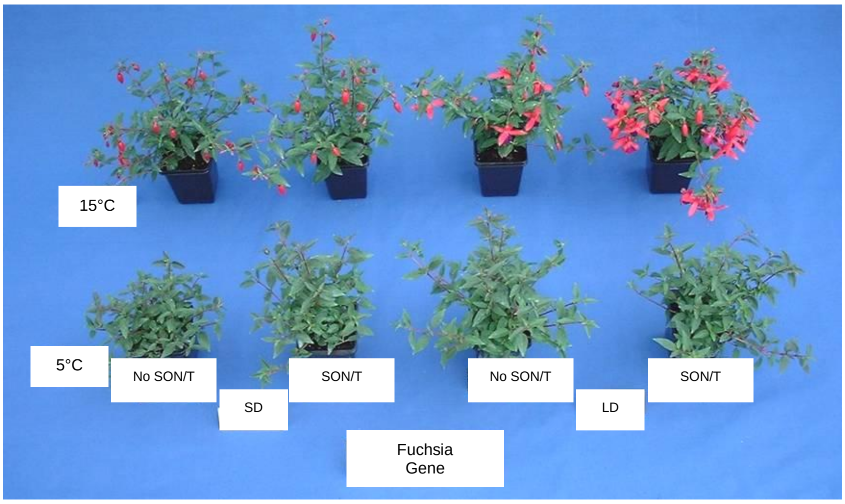


***Figure 27**. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Gene. Photograph taken on 28/04/04.*

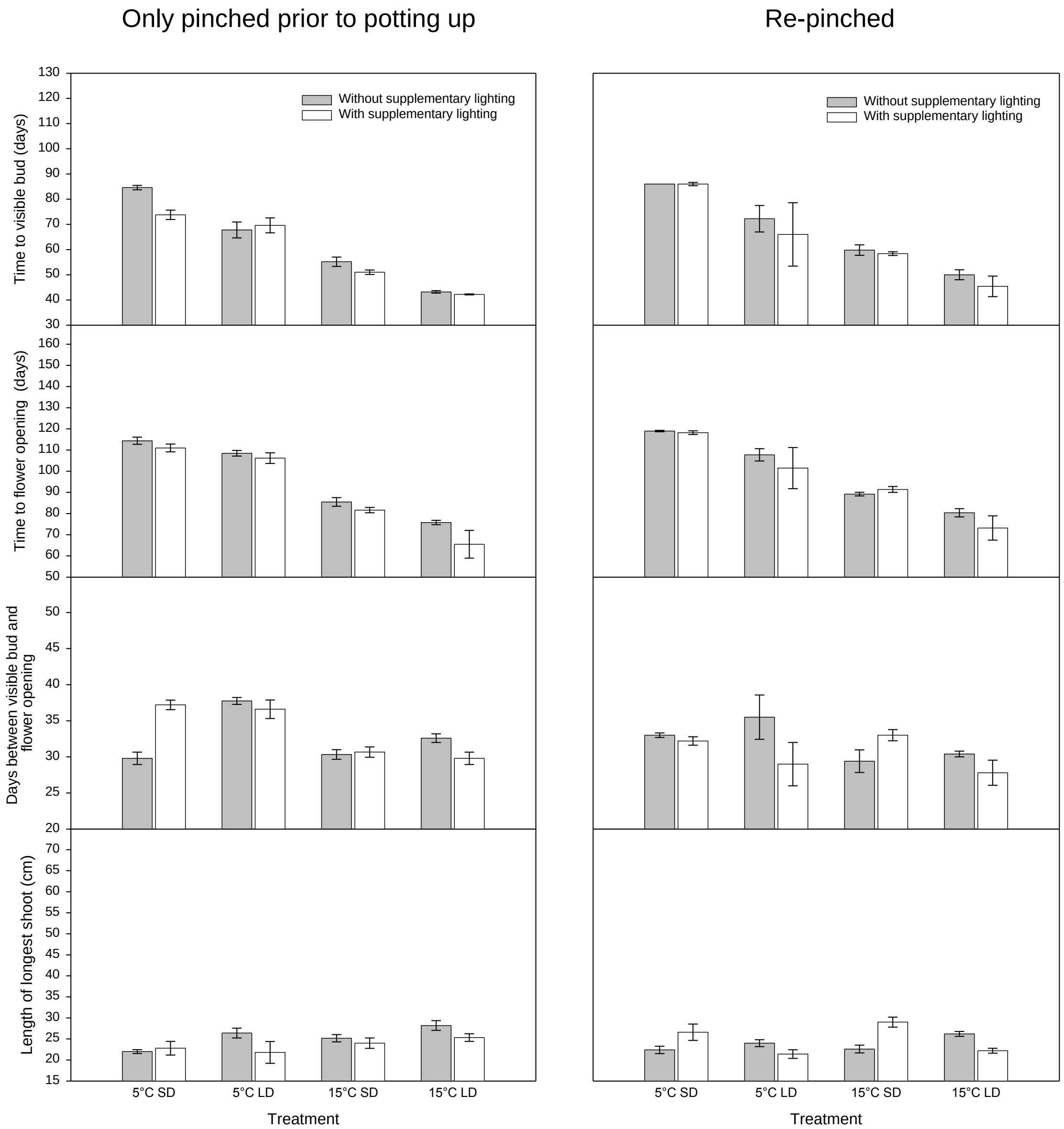


Figure 28. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Gene*

Fuchsia cv. Liza

(Fuchsia x hybrida)

Rooted cuttings of Liza were potted up on 2 February. These had been pinched prior to delivery, although half of the plants were pinched again on 4 March. Pinching delayed bud appearance by 10 days. Buds appeared 27 days earlier in the warmer compartments and on average 17 days earlier under long days. However, the response to daylength was affected by pinching. Long days hastened bud appearance by 24 days in plants that were not re-pinched, compared with 10 days in re-pinched plants.

Temperature was the only treatment to affect the rate of bud development. The time from visible bud to flower opening was hastened by 5 days in the warm compartments. Plants grown at a set-point of 5°C flowered after 124 days from potting up compared with 91 days when grown at 15°C. The effects of daylength on flower opening were similar to those described for bud appearance. Overall supplementary lighting reduced flowering time by 3 days.

The treatments had a negligible effect on the plant height at flowering.

***Figure 29**. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Liza. Photograph taken on 28/04/04.*

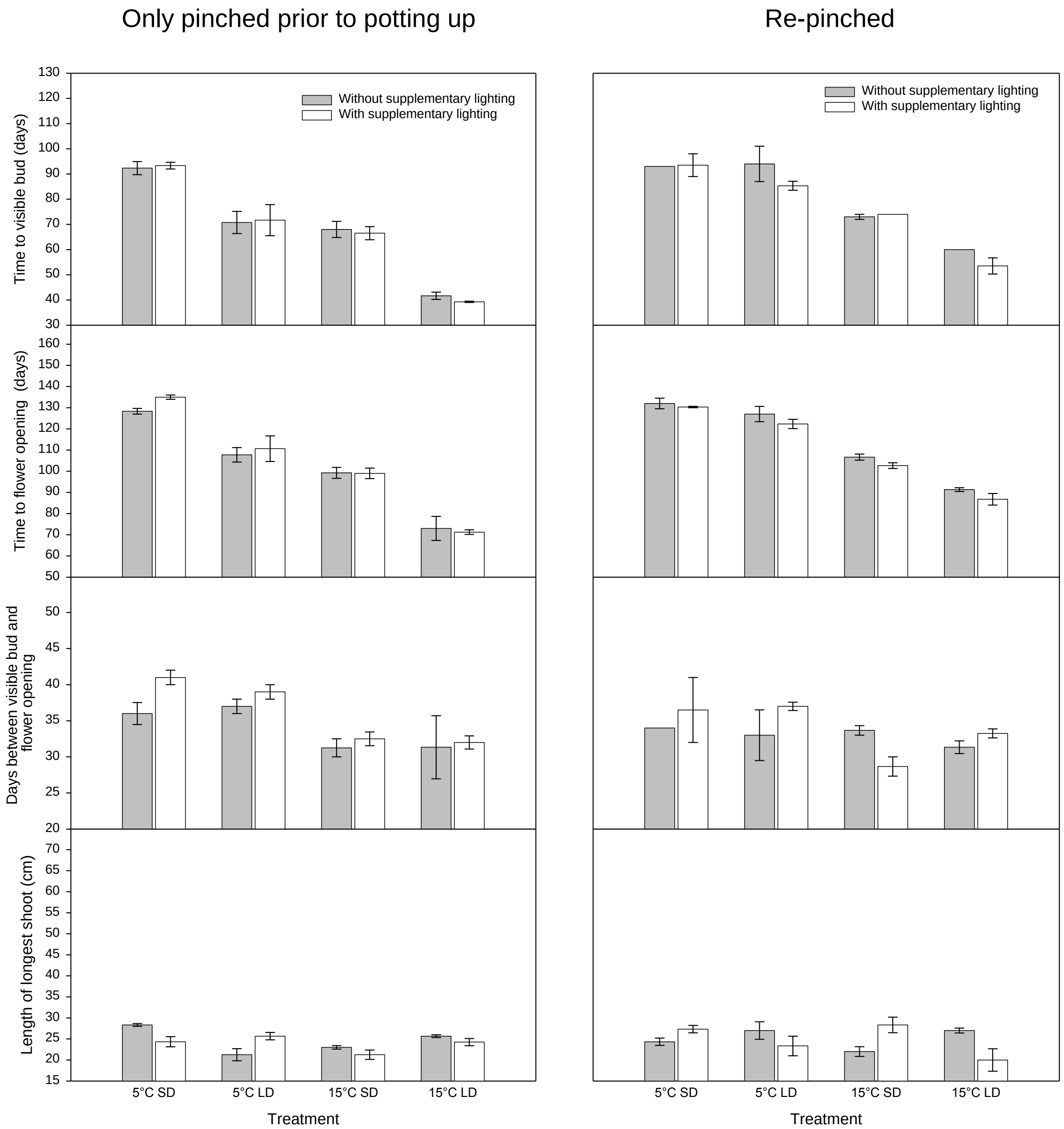


Figure 30. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Liza*

Fuchsia cv. Lyle's Unique

(Fuchsia x hybrida)

Rooted cuttings of Lyle's Unique were potted up on 20 January. These had been pinched prior to delivery, although half of the plants were pinched again on 3 March. Pinching delayed bud appearance by 13 days. Buds appeared on average 11 days earlier in the warmer compartments and 14 days earlier under long days. Again the response to long days was greater in plants that were not re-pinched; 19 compared with 10 days difference between long day and natural daylength plants. Plants that were not re-pinched also showed a bigger impact of temperature. Supplementary lighting hastened the appearance of visible buds by 3 days.

Warmer temperatures hastened the period from bud appearance to flower opening by 4 days. Plants grown at a set-point of 5°C flowered on average after 118 days compared with 103 days at a set-point of 15°C; this difference was greater in plants that were not re-pinched. As daylength and supplementary lighting did not have a significant effect on bud development, their impact on flowering time was similar to that described for bud appearance.

Both temperature and daylength had a significant impact on the shoot length at flowering. Warmer temperatures increased the average length of the longest shoots by 11 cm while long days increased the length by 3 cm.

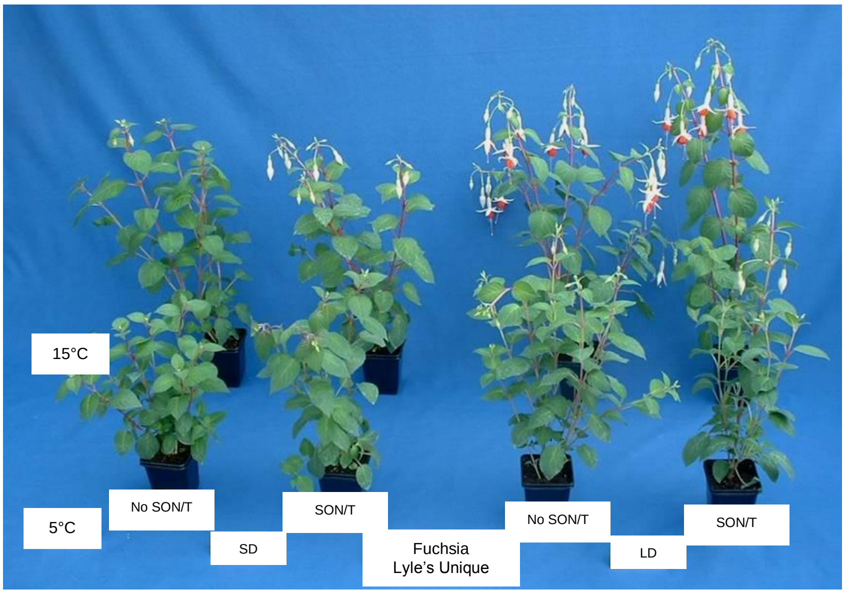


***Figure 31**. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Lyle's Unique. Photograph taken on 10/05/04.*

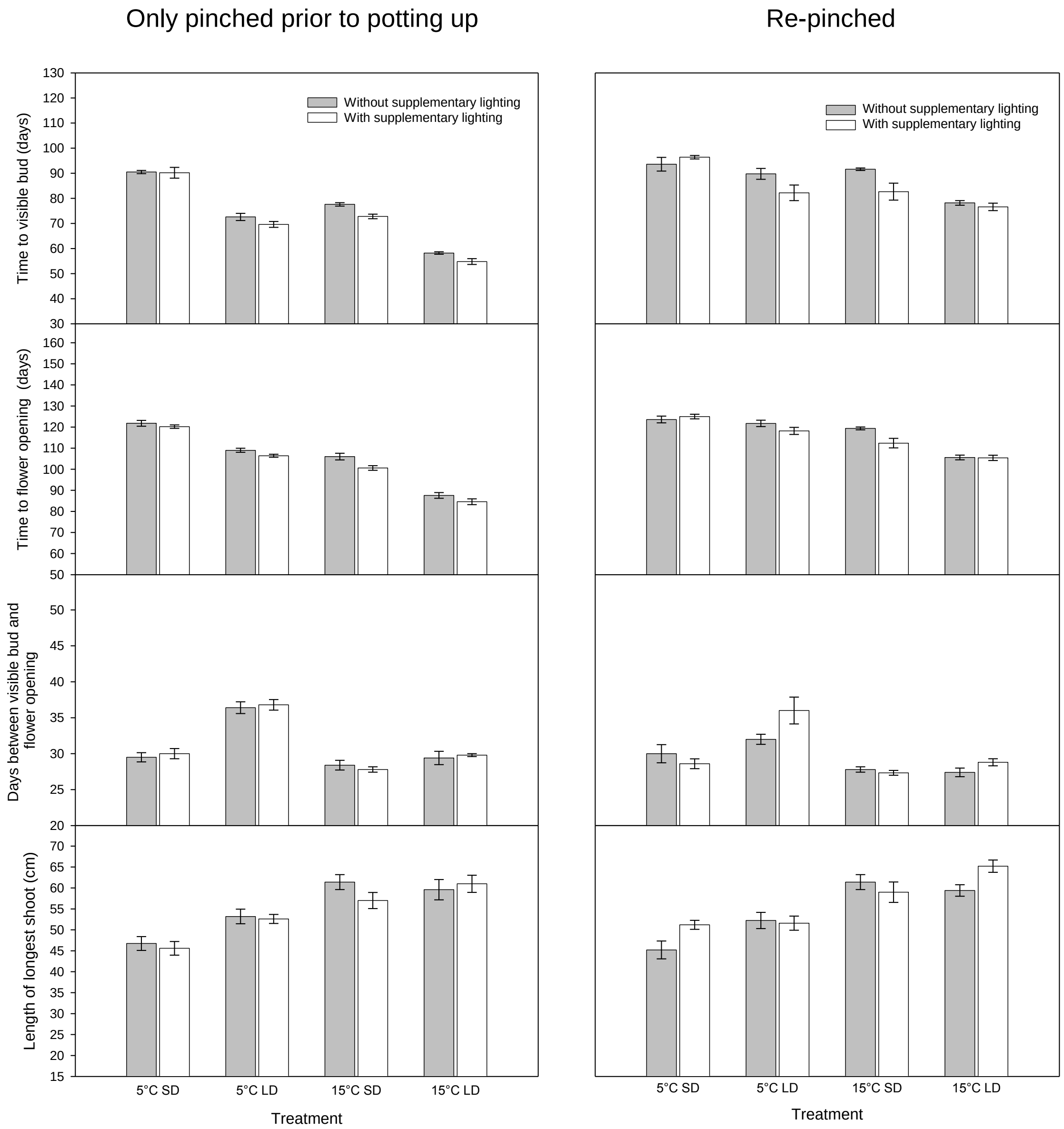


Figure 32. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Lyle's Unique*

Fuchsia cv. Marcia

(Fuchsia x hybrida)

Rooted cuttings of Marcia were potted up on 2 February. These had been pinched prior to delivery, although half of the plants were pinched again on 4 March. Pinching delayed bud appearance by 10 days. Increasing the temperature from a set-point of 5 to 15°C hastened bud appearance by 22 days, while long day lighting hastened bud appearance by 5 days.

The only treatment to have a significant effect on the time from bud appearance to flower opening was temperature. Warmer temperatures hastened this phase by 8 days. Therefore, temperature had the biggest overall effect on the time to flower opening. Plants grown at a set-point of 5°C flowered after 104 days, compared with 75 days at a set-point of 15°C.

Long day lighting increased the plant height by 4cm. Temperature had a smaller effect; plants grown in the warmer compartments were on average 2cm shorter at the time of flowering.

***Figure 33**. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Marcia. Photograph taken on 15/04/04.*

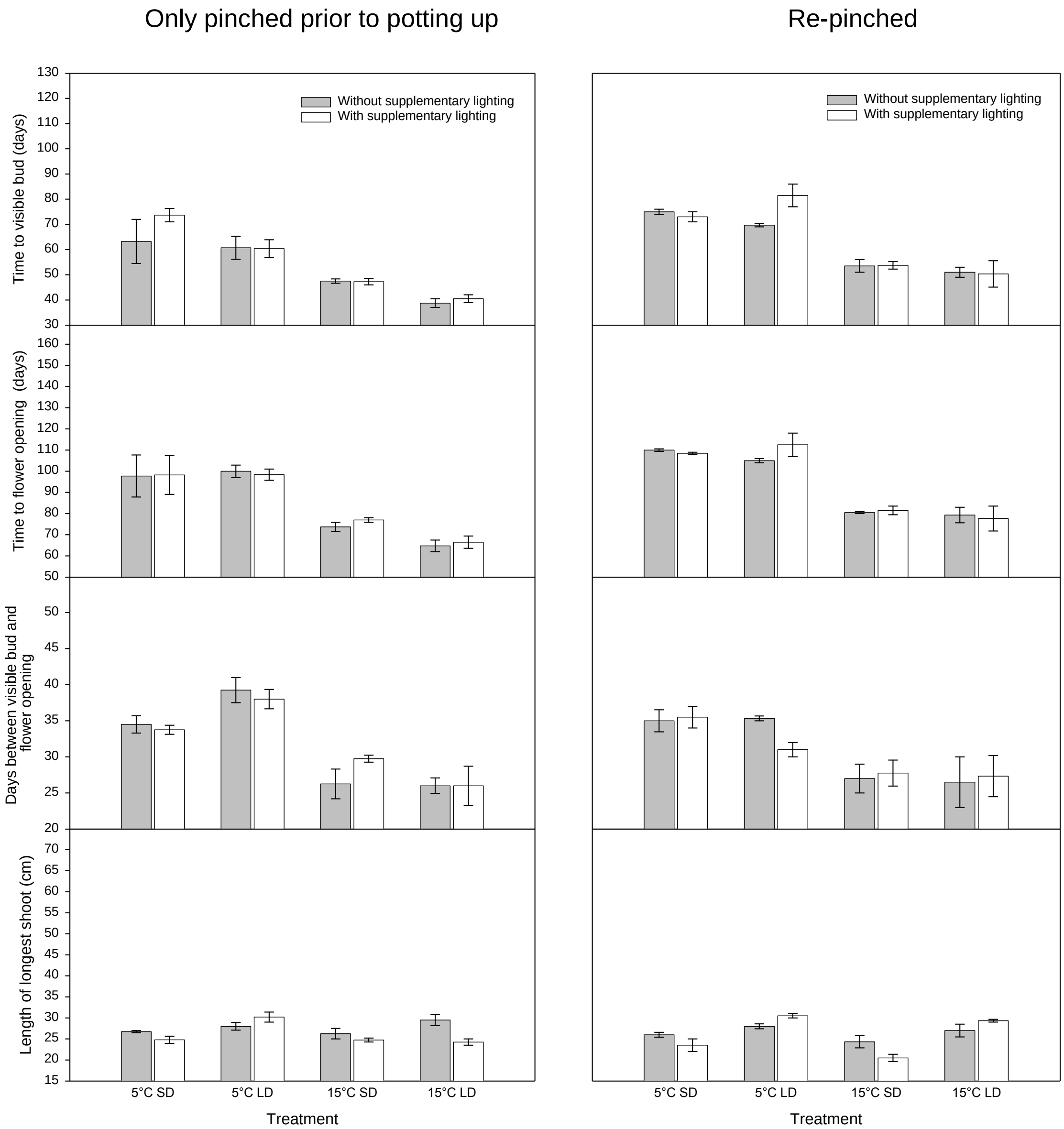


Figure 34. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Marcia*

Fuchsia cv. Maybe Baby

(Fuchsia x hybrida)

Rooted cuttings of Maybe Baby were potted up on 20 January. These had been pinched prior to delivery, although half of the plants were pinched again on 3 March. Pinching delayed bud appearance by 12 days. The time of bud appearance was hastened by 13 days in the warmer compartments and was hastened by 9 days through the use of long day lighting. However, the effect of daylength was more pronounced on plants that had not been pinched a second time. Long days hastened bud appearance by 13 days in plants that were not re-pinched, compared with 6 days in plants that had been re-pinched. Long days also had a greater effect in the warmer compartments, which also tended to hasten bud initiation.

Increasing the temperature hastened bud development, reducing the time from visible bud to flower opening. Plants flowered on average after 123 days in the cool compartments compared with 104 days in the warmer compartments. The effects of daylength on flower opening were similar to those described above for bud appearance.

Plant height was affected by both temperature and daylength. Plants were 8 cm taller in the warmer compartments at the time of flowering. Long day lighting increased plant heights by 5 cm.

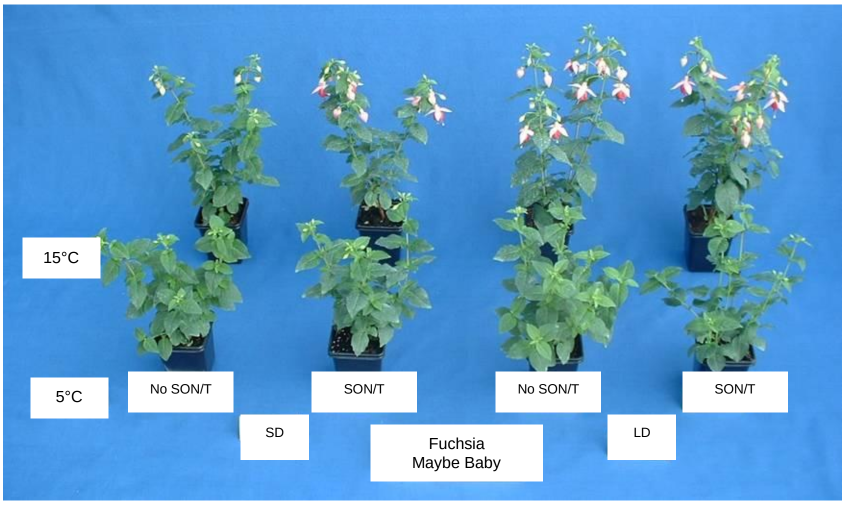


Figure 35. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Maybe Baby. Photograph taken on 10/05/04.*

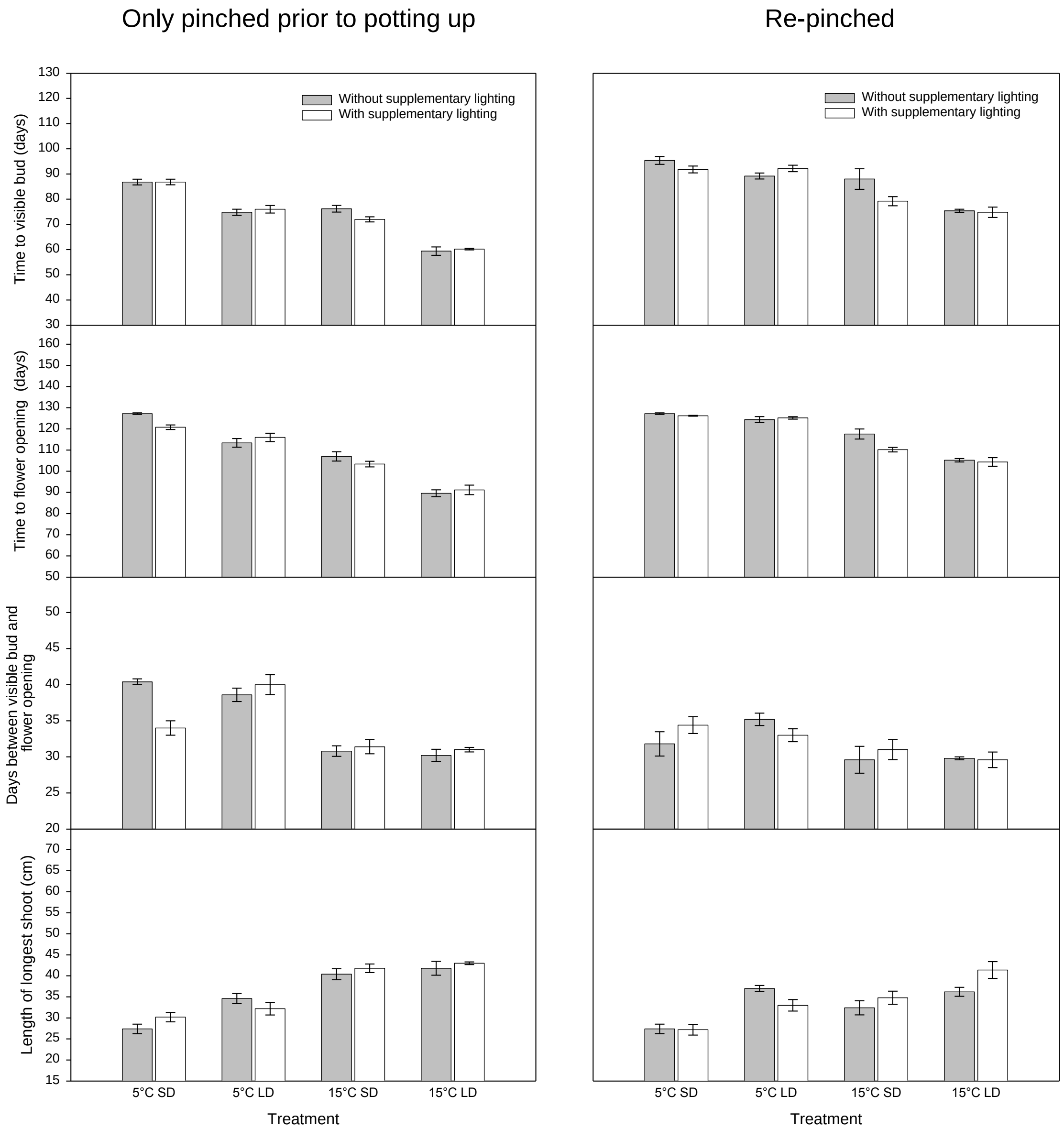


Figure 36. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Maybe Baby*

Fuchsia cv. Nice 'n' Easy

(Fuchsia x hybrida)

Rooted cuttings of Nice 'n' Easy were potted up on 22 January and then pinched on 3 February. Buds were visible on average after 88 days although this duration was significantly affected by temperature and daylength. These two factors interacted such that plants were more responsive to long days in the warm compartments. Long day lighting hastened flowering by 5 days in the 5°C compartments compared with 12 days in the 15°C compartments. Increasing the temperature set-point hastened bud appearance by 25 days on average, although this difference was greater under long days. Supplementary lighting hastened bud appearance by 5 days.

The rate of flower development was affected by temperature; increasing the temperature set-point from 5 to 15°C hastened flower development by 3 days. Overall warmer temperatures hastened flowering by 29 days and long days hastened flower opening by 8 days, although these to treatments interacted with one another (see above paragraph). Due to the effect on time of bud appearance, supplementary lighting hastened flower opening by 5 days.

Figure 37*. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Nice 'n' Easy. Photograph taken on 28/04/04.*

Both warmer temperatures and long day lighting increased plant height. Increasing the temperature set-point from 5 to 15°C increased the average height by 4 cm while lighting with tungsten lamps increased height by 5 cm.

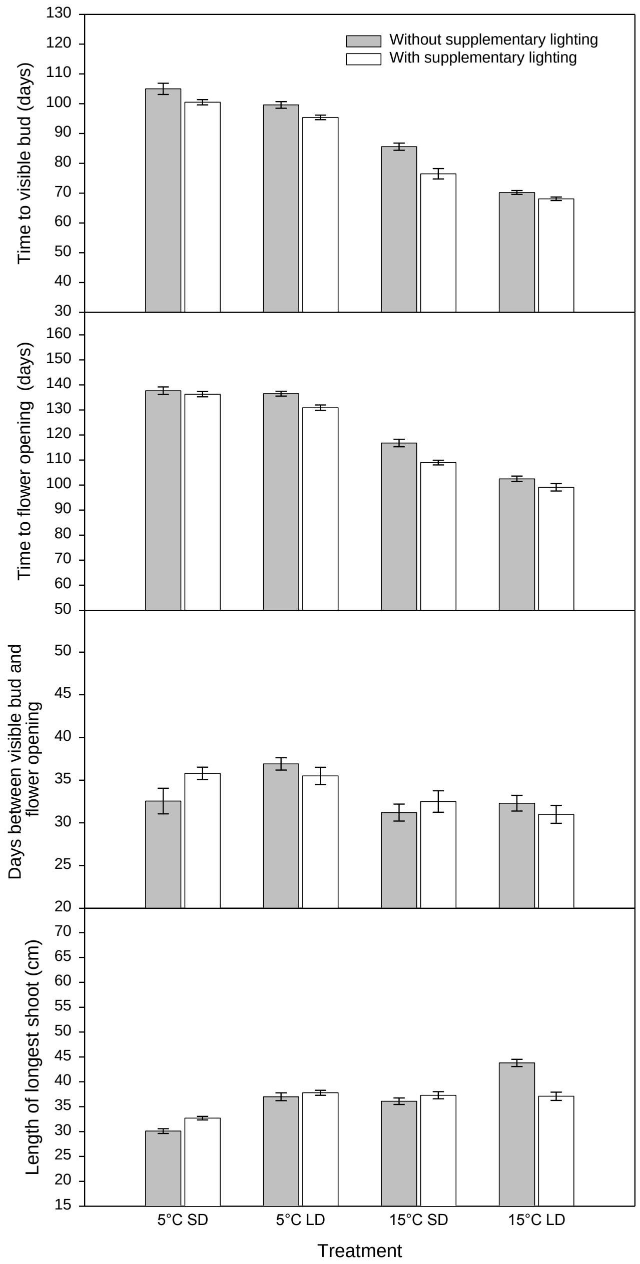


Figure 38. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Nice 'n' Easy*

Fuchsia cv. Patio Princess

(Fuchsia x hybrida)

Rooted cuttings of Patio Princes were potted up on 22 January and pinched on 3 February. These plants were sourced from two different propagators, one batch of plants was in bigger plugs and the plants were larger at the time of delivery. The larger plugs did initiate buds sooner, although the difference between batches was only 4 days.

All of the treatments had a significant impact on the time of visible bud. Buds appeared 21 days sooner in the warm compartments, and long days hastened bud appearance by 15 days. Supplementary lighting had a significant effect, although interestingly this was only the case in the smaller plugs. In these plants supplementary lighting hastened bud appearance by 4 days.

Increasing the temperature regime hastened bud development by 6 days. Overall plants flowered after 121 days at a set-point of 5°C compared with 94 days at 15°C.

Long day lighting with tungsten bulbs increased plant height by 2 cm, while increasing the temperature increased the height by 3 cm on average.

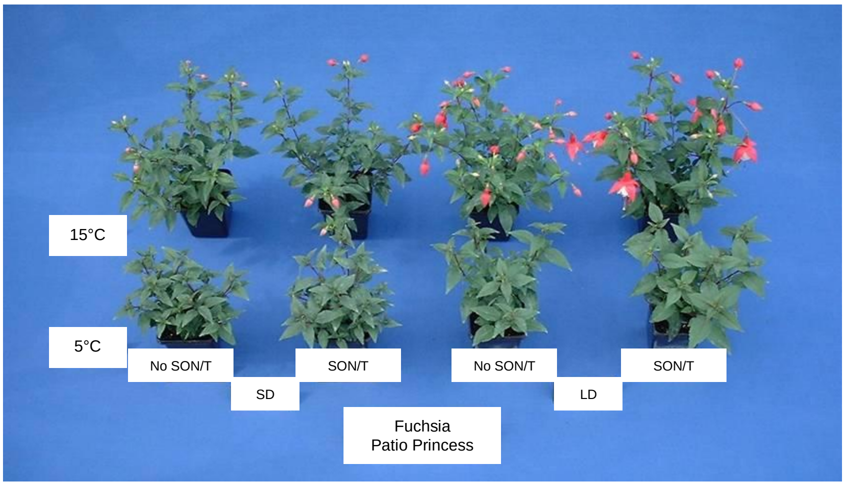


***Figure 39**. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Patio Princess. Photograph taken on 15/04/04.*

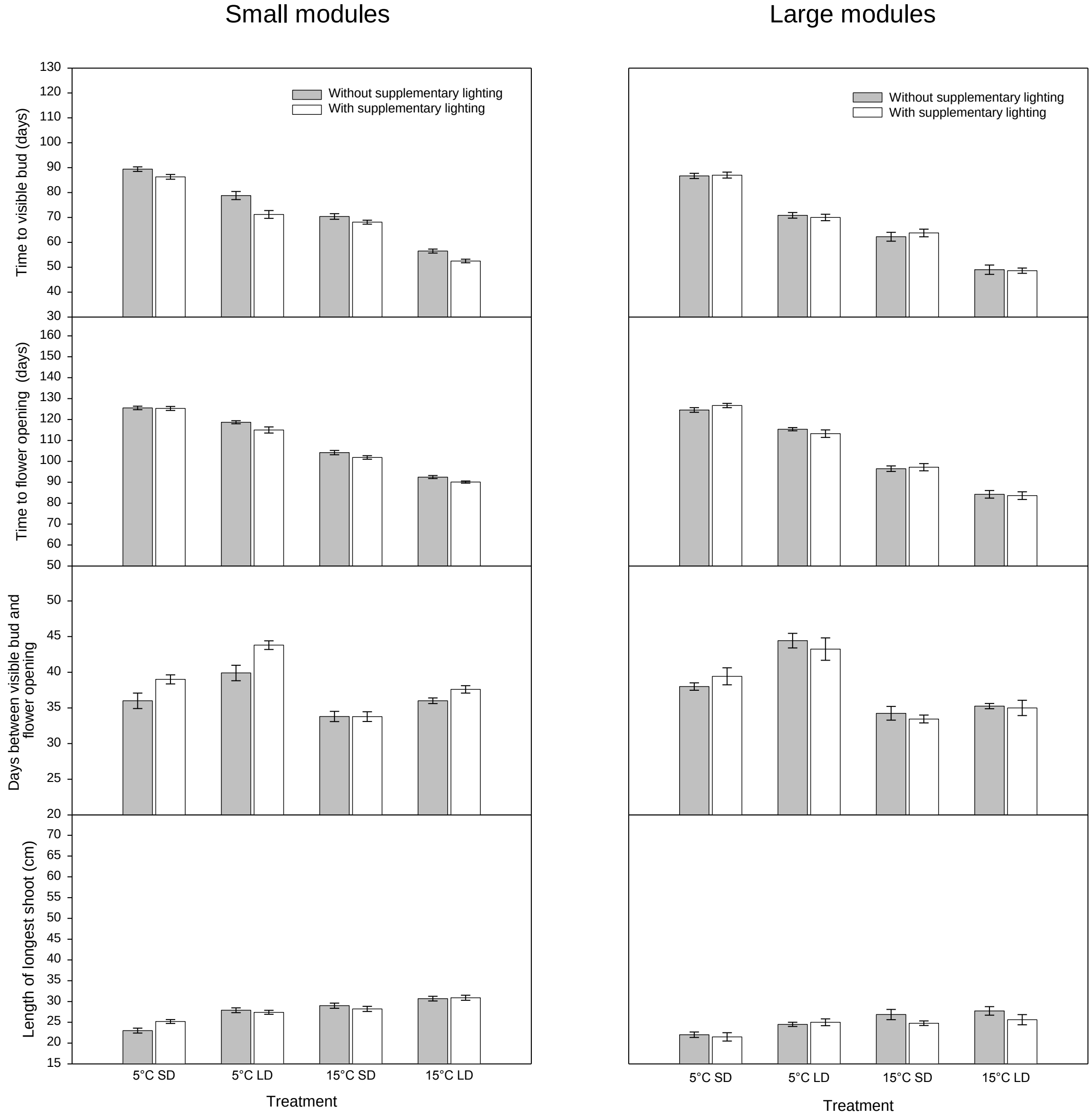


Figure 40. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Patio Princess*

Fuchsia cv. Pink Marshmallow

(Fuchsia x hybrida)

Rooted cuttings of Pink Marshmallow were potted up on 22 January. These had been pinched prior to delivery, although half of the plants were pinched again on 3 March. Pinching delayed bud appearance by 8 days. The time of bud appearance was also affected by temperature and daylength. On average buds appeared 18 days sooner in the warm compartments and long days hastened bud appearance by 15 days. However, the response to daylength was greater in the warmer compartments and the effect of temperature was greater in the long day compartments. When grown at a set-point of 5°C long days hastened bud appearance by 9 days compared with 21 days at a set-point of 15°C. Increasing the temperature hastened bud appearance by 12 days under a natural photoperiod, compared with 24 days under long day conditions.

The only treatment to significantly affect the rate of bud development was increased temperature. The time from visible bud to flower opening was hastened by 5 days in the warmer compartments. Due to effects on bud appearance and flower development, increasing the heating temperature set-point from 5 to 15°C reduced the time to flower opening from 121 days to 98 days.

The longest shoots were 5 cm longer in the warmer compartments. Long day lighting decreased shoot lengths at flowering by 6 cm.

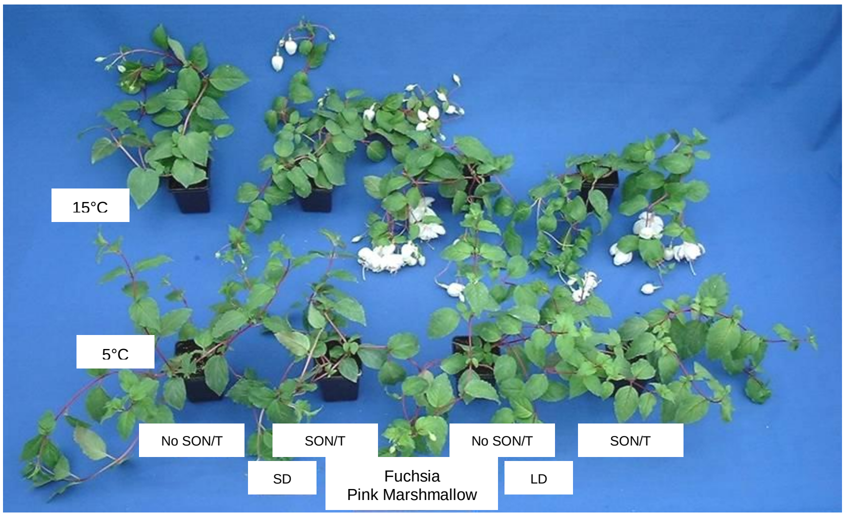


***Figure 41**. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Pink Marshmallow. Photograph taken on 28/04/04.*

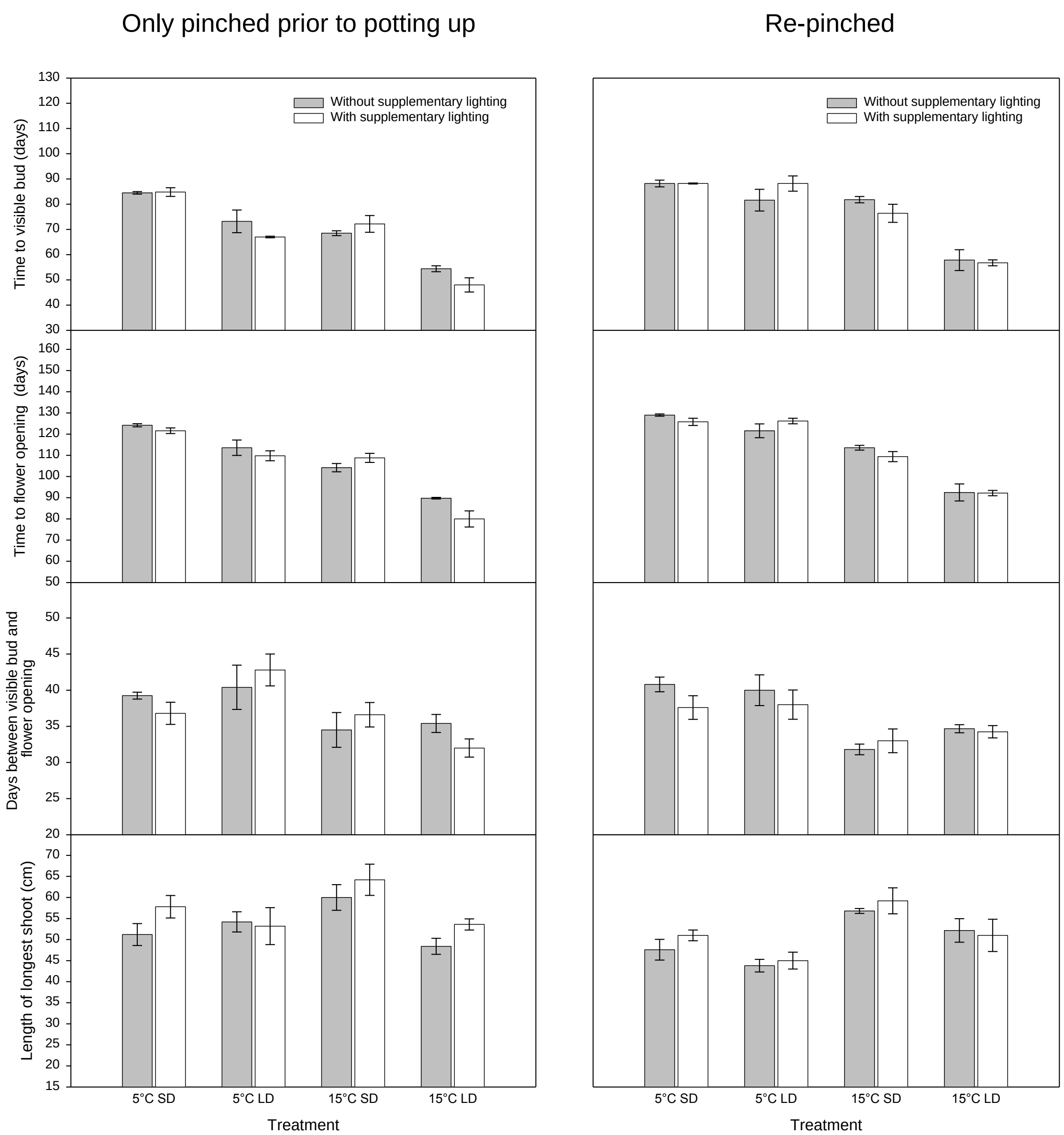


Figure 42. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Pink Marshmallow*

Fuchsia cv. Pink Spangles

(Fuchsia x hybrida)

Rooted cuttings of Pink Spangles were potted up on 22 January. These were then pinched on 28 January. Both temperature and daylength affected the time of visible bud; again these two treatments interacted with one another. Long days hastened bud appearance by 10 days at a set-point of 5°C, compared with 20 days at a set-point of 15°C. Increasing the temperature regime hastened bud appearance by 19 days under a natural photoperiod, compared with 29 days under long days. Supplementary lighting hastened bud appearance, although only by 2 days.

The rate of flower bud development was hastened by increasing the temperature although the difference was only 2 days.

Plant height was affected by both temperature and daylength. Plants were 3 cm taller in the warmer compartments and were 4cm taller as a result of the long day treatment.

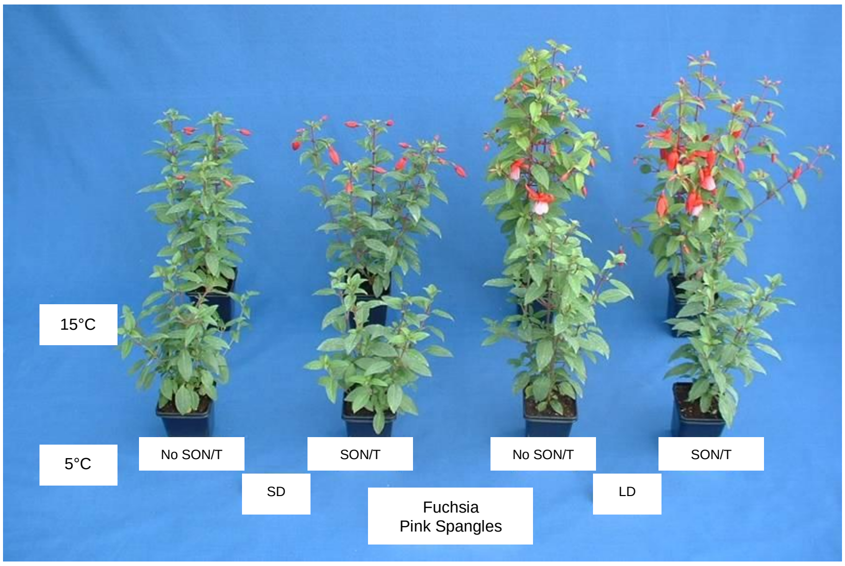


***Figure 43**. The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Pink Spangles. Photograph taken on 10/05/04.*

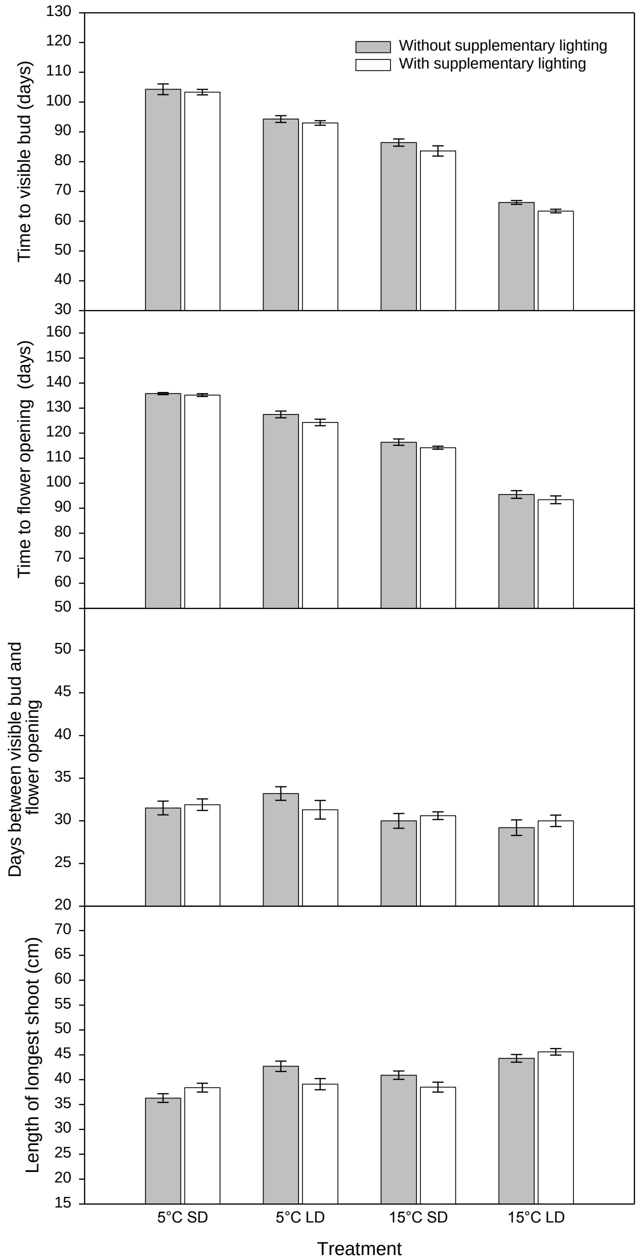


Figure 44. *The effect of temperature, daylength and supplementary lighting on Fuchsia cv. Pink Spangles*

Lobelia cv. Richardii

(Lobelia erinus)

Lobelia is a short lived herbaceous species. Runkle *et al*. (1999) investigated the flowering response of *Lobelia x speciosa* Sweet 'Compliment Scarlet' and defined this as a quantitative long day plant. Plants that were initially held at 5°C before being grown on at 20°C developed more flowers; a cold treatment of more than 9 weeks could, in part, substitute for long days.

Rooted cuttings of Lobelia cv. Richardii were potted up and placed into the treatments on 20 January. These plants had been pinched prior to delivery. The time to visible bud was hastened by long days, more so in the warm compartments. In the compartments set to 5°C longs days hastened bud appearance by 19 days compared with 27 days in the 15°C compartments. Increasing the temperature hastened bud appearance by 9 days in the long day compartments.

The effect of daylength on the rate of flower development was less pronounced. Despite having hastened bud appearance, interestingly long days appeared to delay flower development in the cooler glasshouse compartments (by 8 days). Temperature had a greater impact on the length of this phase. Flowers developed more quickly in the warmer compartments; flower development was hastened on average by 14 days. As a result the time of flower opening was significantly affected by both temperature and daylength. Plants grown under long days at 15°C flowered after 65 days (from the start of the experiment) compared with 104 days at 5°C with a natural daylength.

Figure 45*. The effect of temperature, daylength and supplementary lighting on Lobelia cv. Richardii. Photograph taken on 01/04/04.*

Increasing the temperature set-point from 5 to 15°C increased plant growth and increased the length of the longest shoot at flowering from 40 to 49 cm.

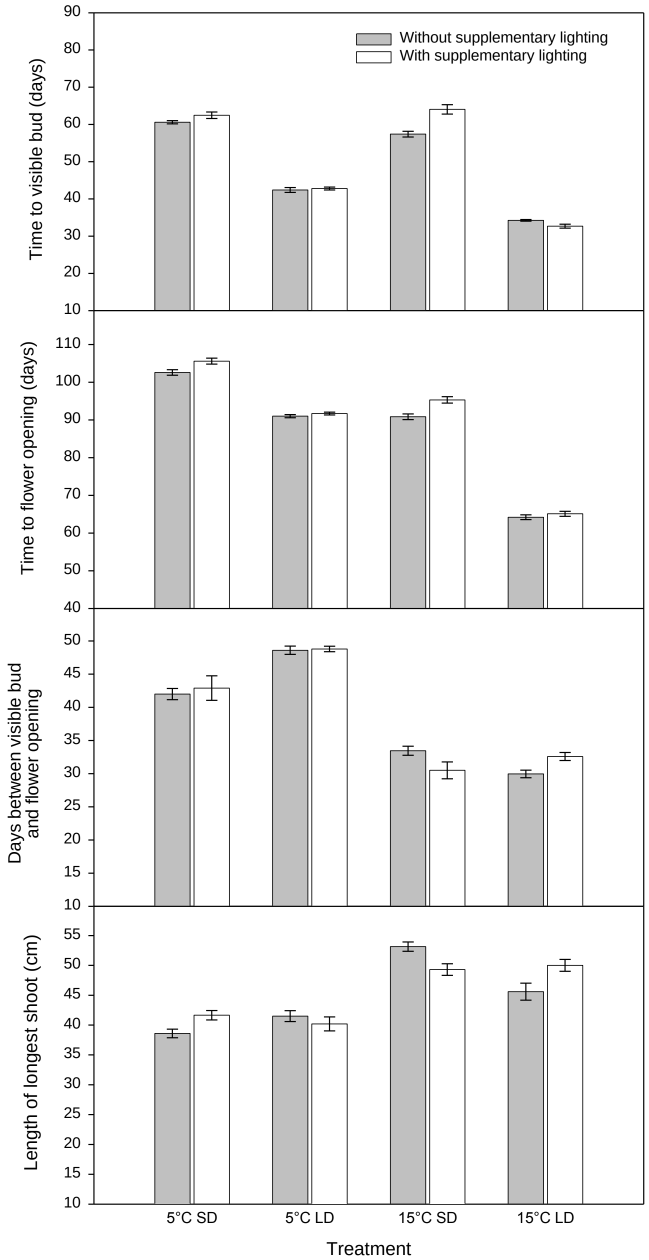


Figure 46. *The effect of temperature, daylength and supplementary lighting on Lobelia cv. Richardii*

Lobelia cv. White Star

(Lobelia erinus)

Rooted cuttings of Lobelia cv White Star were potted up on 20 January. These plants were also pinched prior to delivery. As with cv. Richardii, long days hastened the appearance of flower buds. Buds appeared after 36 days under long days compared with 58 days under a natural daylength. Temperature also had a significant effect hastening bud appearance by 16 days.

Again temperature had the biggest impact on the development of flower buds; increasing the temperature hastened the bud development by 8 days. As with cv. Richardii, despite having hastened bud appearance, long days delayed flower development in the cooler glasshouse compartments (by 8 days). Supplementary lighting hastened bud development by 2 days.

Overall plants flowered around 23 days earlier in the 15°C compartments. Long days hastened flower opening by on average 17 days, although the difference was greater in the warm compartments. Due to the small effect on bud development supplementary lighting also hastened flower opening by a couple of days. None of the treatments had a significant effect on the length of the longest shoot at marketing.

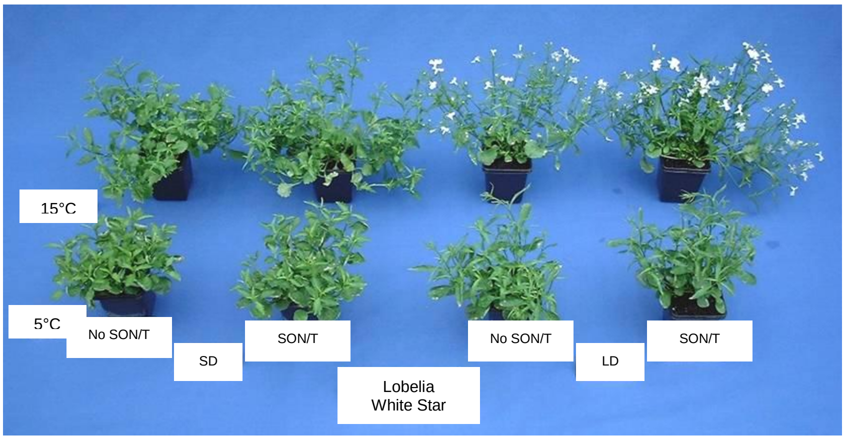


***Figure 47**. The effect of temperature, daylength and supplementary lighting on Lobelia cv. White Star. Photograph taken on 01/04/04.*

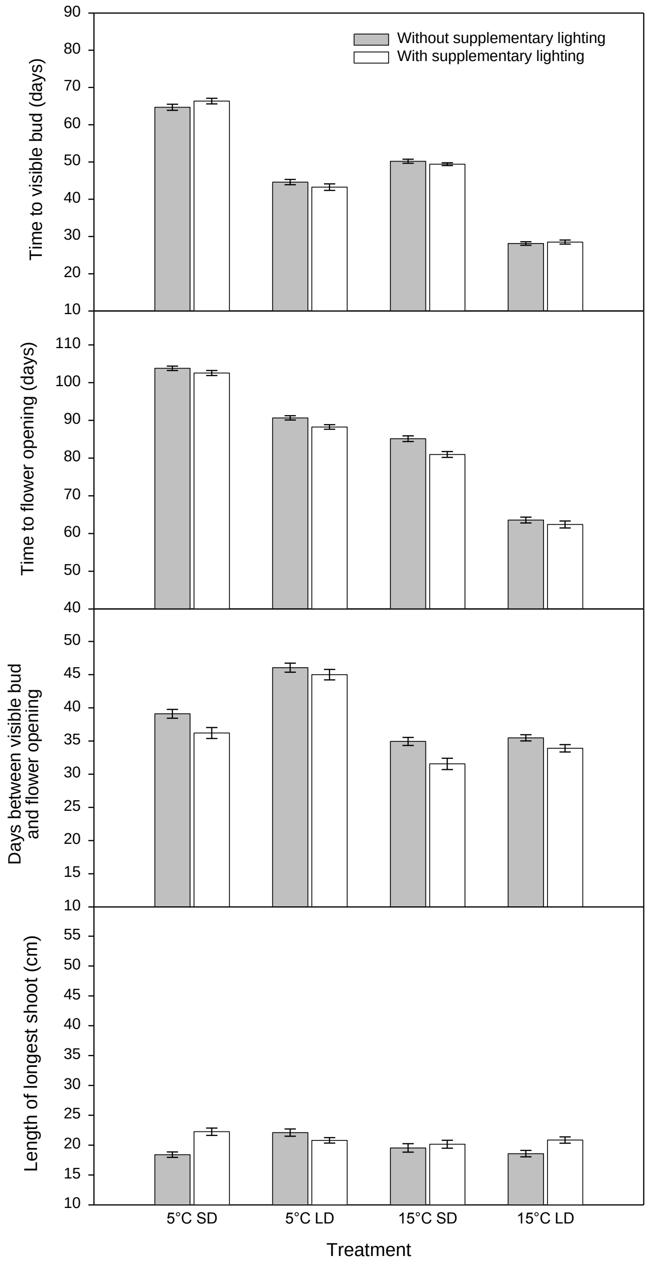


Figure 48. *The effect of temperature, daylength and supplementary lighting on Lobelia cv. White Star*

Lotus

(Lotus berthelotii)

Lotus, also know as 'Coral Gem' and 'Parrot's Beak', is a spreading perennial which originates from the Canary Islands. Rooted cuttings were potted up on 19 January. These had been pinched prior to delivery, although half of the plants were pinched again on 3 March. Not all of the plants had flowered by the end of June (after 162 days within the different treatments) and many of these plants did not even have visible buds and so the experiment was terminated on this day. Therefore Figure 50 also contains information about the percentage of plants which had buds and open flowers by day 162.

Lower temperatures appeared to promote flower initiation. In the 5°C compartments on average 95% of plants developed flower buds, while in the 15°C compartments only 68% of plants had visible buds. However, not all of these buds went on to produce open flowers; in the 15°C compartments only 20% of plants flowered. Flowering also appeared to be promoted by natural short days; long day lighting reduced the percentage of plants with buds from 99 to 65%. Due to the combined effects of temperature and daylength, 100% of plants in the 5°C/SD compartment flowered, compared with just 11% in the 15°C/LD compartment. Supplementary lighting also appeared to promote flowering, increasing the percentage of plants (across all treatments) with buds from 71 to 92%. However, the effect of supplementary lighting was more noticeable in certain compartments. In the 5°C compartment with long day lighting, supplementary lighting increased the percentage of plants that flowered from 0 to 90% when repinched.

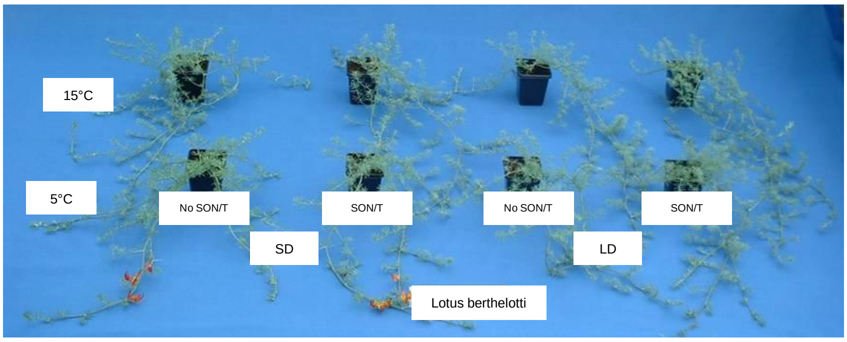


***Figure 49**. The effect of temperature, daylength and supplementary lighting on Lotus. Photograph taken on 25/05/04.*

Increasing the temperature regime increased the average shoot length by 20 cm. Long day lighting also had a significant effect, increasing the average shoot length by 13 cm, although this effect was more pronounced in the cooler compartments.

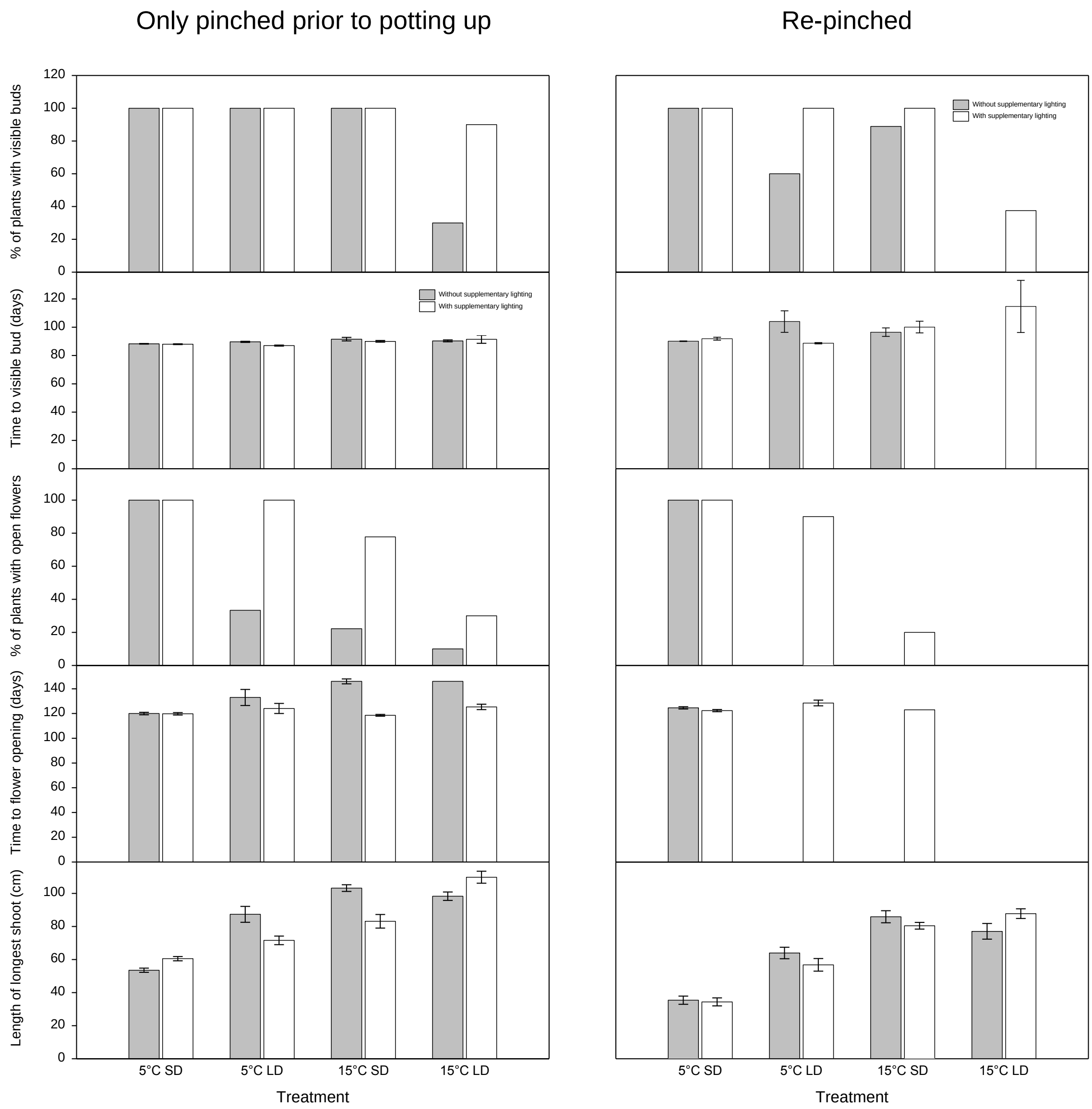


Figure 50. *The effect of temperature, daylength and supplementary lighting on Lotus*

Nemesia cv. Blue Lagoon

(*Nemesia fruticans*)

Nemesia is a short lived perennial originating from South Africa which is grown in the UK as a half hardy annual. It likes sunny conditions and fertile well-drained soil.

Rooted cuttings were potted up on 6 January and then pinched on 23 January. Buds appeared earlier in the warm compartments; higher temperatures hastened bud appearance by on average 9 days. There was also a significant effect of supplementary lighting such that lit plants had visible buds on average 6 days earlier than unlit plants. Daylength did not have a significant effect on the time of visible bud.

The time from visible bud to flower opening was hastened by warm temperatures. As a result the plants in the 15°C compartments flowered 22 days earlier than those in the 5°C compartments. Flower development was also affected slightly by daylength; plants grown under long days flowered a couple of days before those under short day conditions. Supplementary lighting did not affect the rate of flower bud development, although the lit plants still flowered 6 days earlier due to the fact that buds appeared sooner.

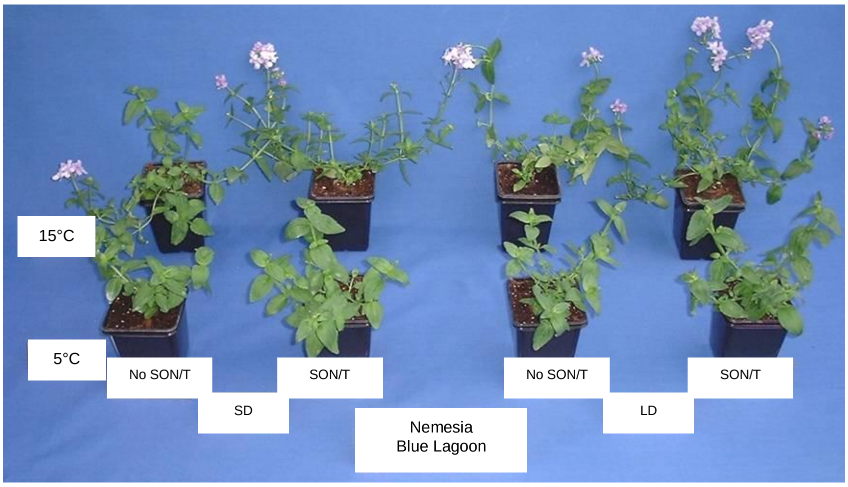


Figure 51*. The effect of temperature, daylength and supplementary lighting on Nemesia cv. Blue Lagoon. Photograph taken on 04/03/04.*

The length of the longest shoot at marketing was significantly affected by temperature, daylength and supplementary lighting. Shoot length increased by on average 7 cm in the 15°C compartments. Long day lighting extended shoots by 4 cm, and supplementary lighting caused around 3 cm extra growth.

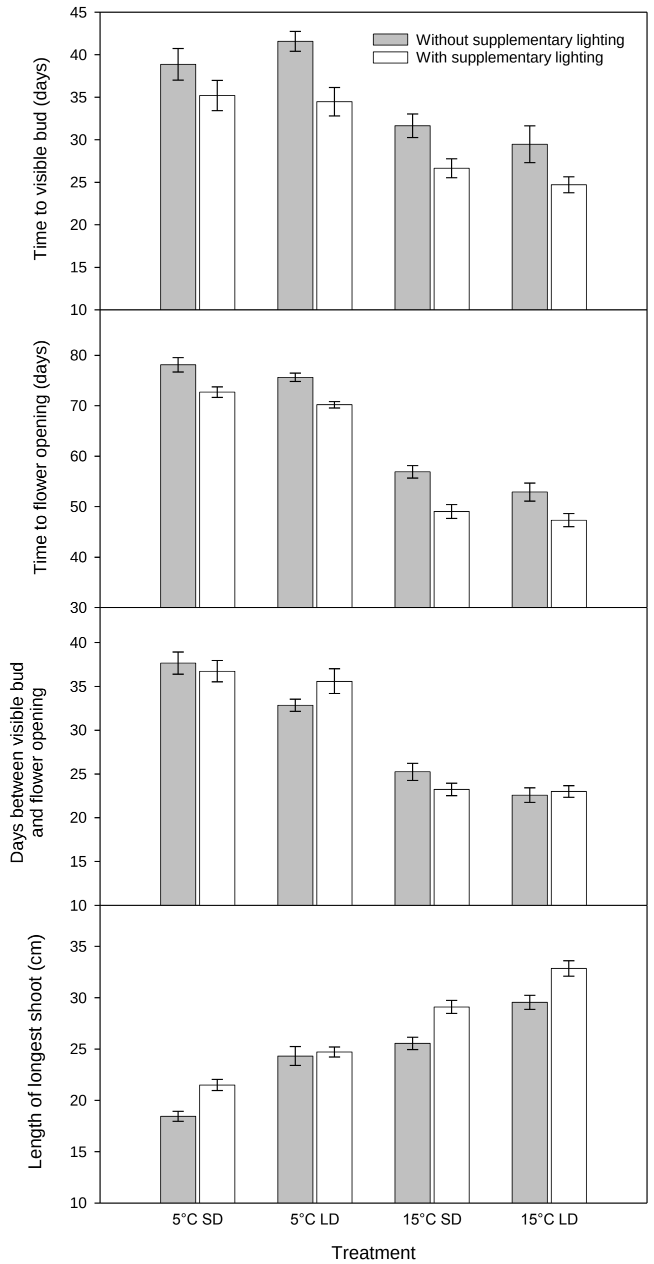


Figure 52. *The effect of temperature, daylength and supplementary lighting on Nemesia cv. Blue Lagoon.*

Petunia cv. Surfinia® Blue

(Petunia x hybrida x P. pendula)

Surfinia or trailing petunias first became widely available in the early 1990's and have increased in popularity due to their vigour and flower performance. Trailing petunias are long day plants; short days and cool temperatures delay flowering. The environment can also affect habit as plants grown under short days tend to have more branches and be more compact; this is more noticeable in warmer environments (Adams *et al*., 1997).

Rooted cuttings which had been pinched before delivery were potted up on 7 January. Temperature and daylength had a marked effect on the time buds were first visible, although the response to daylength was affected by temperature and vice versa. In compartments with a 15°C set-point, long days hastened bud appearance by 46 days, compared with 16 days in the cooler compartments. When grown under long days, increasing the temperature set-point from 5 to 15°C hastened bud appearance by 27 days, while under natural daylengths temperature appeared to have little effect. Although the latter response is unusual, the data are in agreement with the findings of Adams *et al*. (1997).

Long days appeared to delay flower development by 6 days, although this result may be an artefact. Temperature also significantly affected the rate of flower development. Plants grown at 15°C with long days flowered on average after 62 days, while those grown at 5°C under short days took 109 days to flower. Supplementary lighting did not have a significant effect on flowering.

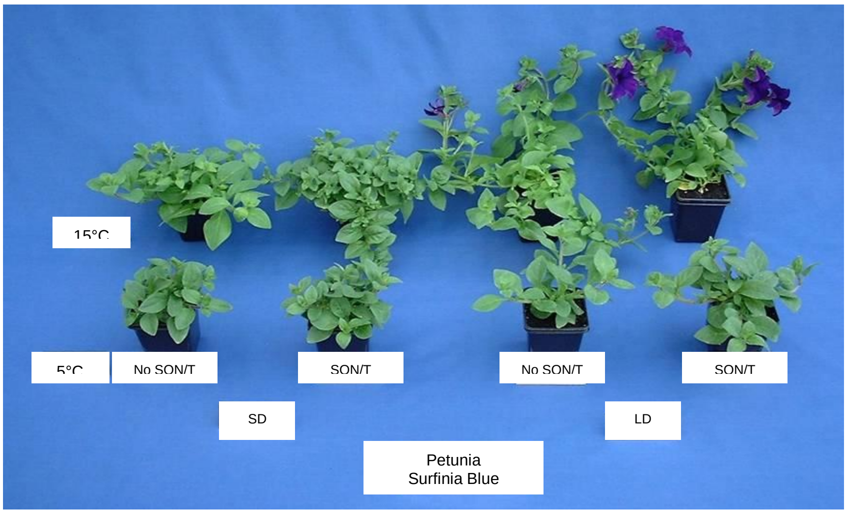


Figure 57*. The effect of temperature, daylength and supplementary lighting on Blue Surfinia. Photograph taken on 12/03/04.*

Temperature had a marked effect on plant growth and morphology. Plants grown under the warmer temperature regime had shoots that were on average 18 cm longer. The use of long day lighting also increased the length of the longest shoots by 5 cm.

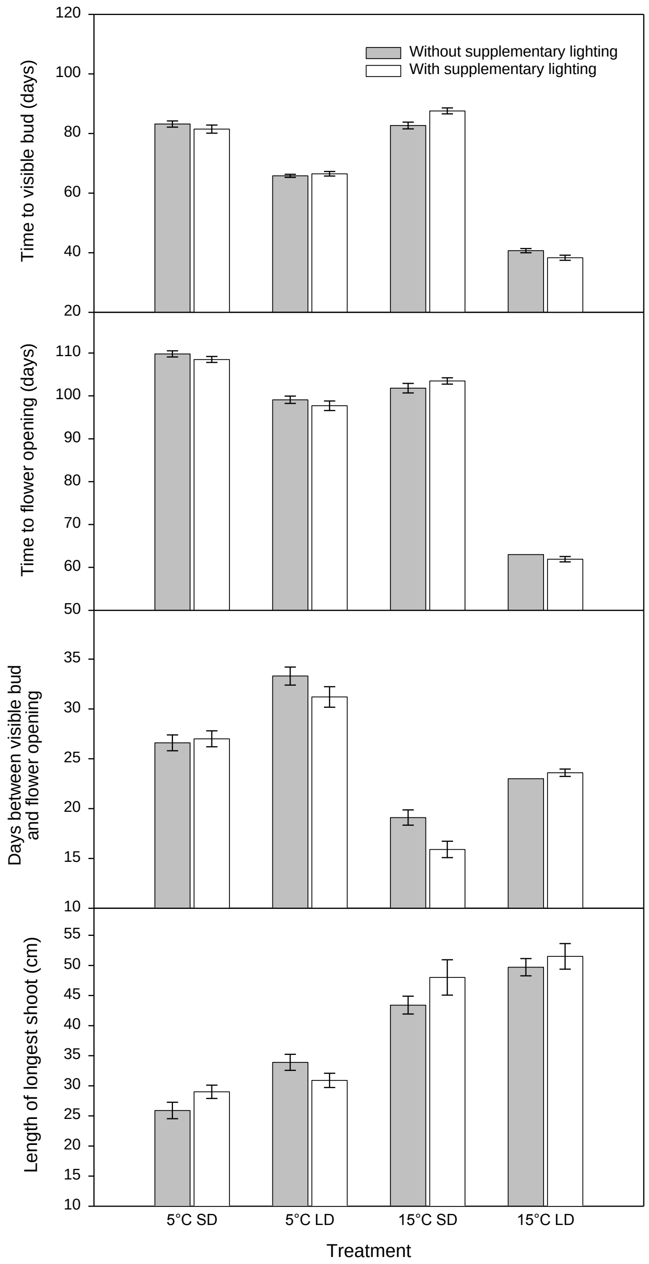


Figure 58. *The effect of temperature, daylength and supplementary lighting on Blue Surfinia.*

Sanvitalia cv. Aztec Gold
(Sanvitalia speciosa)

Sanvitalia or 'Creeping Zinnia' are trailing annuals which originate from Central America. Rooted cuttings were potted up and treatments started on 22 January. The time of visible bud was dramatically hastened in the warmer compartments. Buds were recorded 28 days earlier in the 15°C compartments, which almost halved the length of this phase; this difference was greater (35 days) in the natural daylength compartments. The use of long days also significantly hastened bud appearance. This response interacted with temperature, such that long days hastened bud appearance by 14 days in the cool compartments, but had comparatively little affect (2 days earlier) when plants were grown at a set-point of 15°C.

Daylength had no effect on the rate of bud development, although this phase was hastened by warm temperatures and supplementary lighting. Buds developed around 5 days quicker in the 15°C compartments and 3 days quicker with supplementary lighting.

There were significant effects of temperature, daylength and supplementary lighting on the overall time to flower opening. The warm compartments flowered on average after 53 days compared with 86 days in the cooler compartments. Overall long days hastened flower opening by 12 and 2 days at 5 and 15°C set-points, respectively. Supplementary lighting reduced the flowering time from 71 to 68 days.

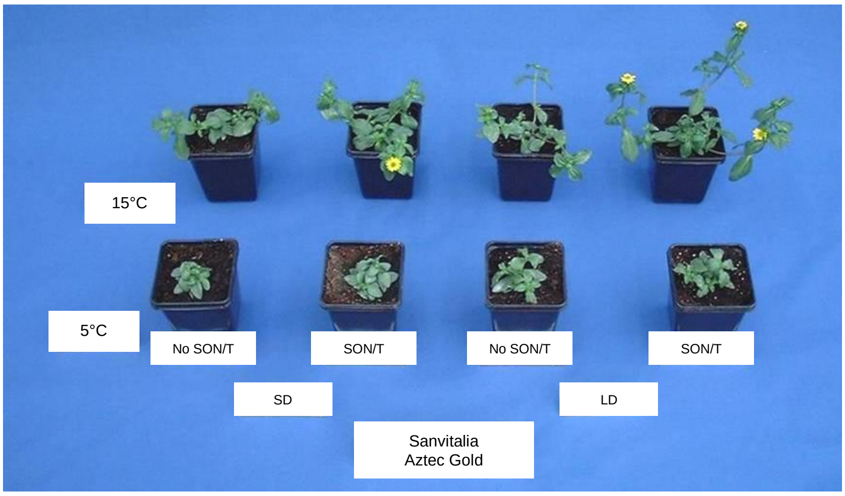


***Figure 53**. The effect of temperature, daylength and supplementary lighting on Sanvitalia cv. Aztec Gold. Photograph taken on 19/03/04.*

The length of the longest shoot at marketing was significantly affected by the temperature; the plants grown at a set-point of 15°C were on average 5 cm longer.

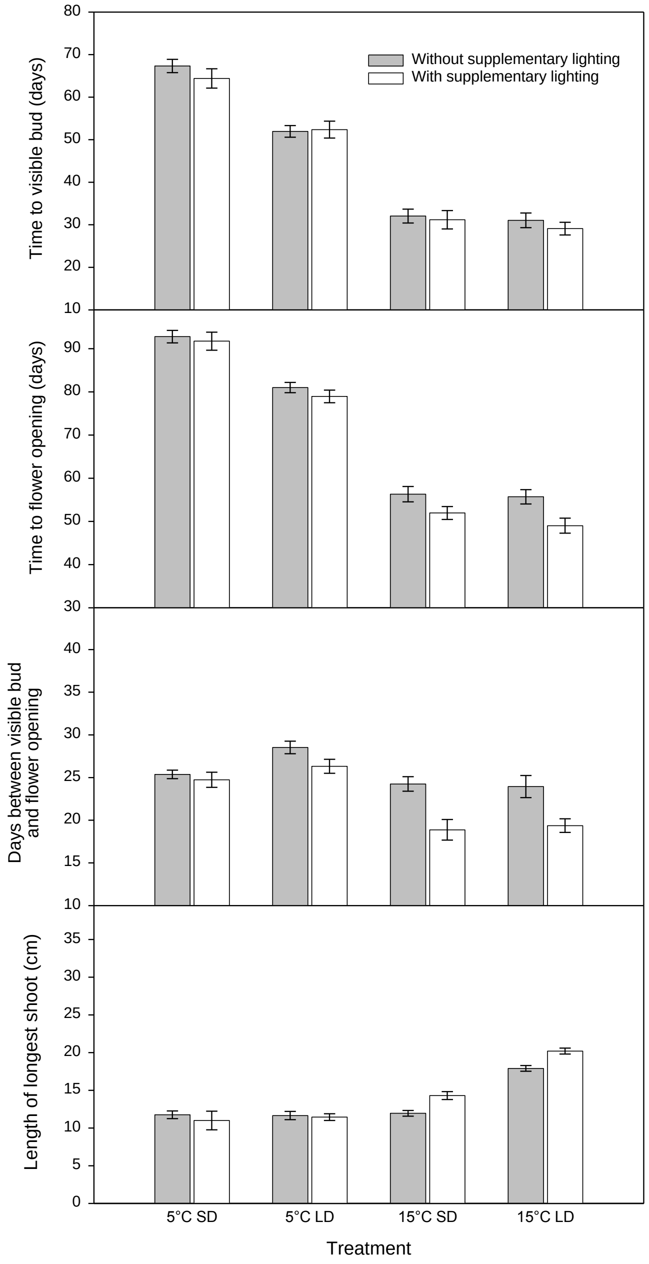


Figure 54. *The effect of temperature, daylength and supplementary lighting on Sanvitalia cv. Aztec Gold*

Scaevola cv. Brilliant

(Scaevola aemula)

Scaevola otherwise know as 'Fan Flower' is an annual which originates from Australia. Rooted cuttings, which were pinched prior to delivery, were potted up on 6 January. According to Hamrick (2003) Scaevola are day neutral, however, our results challenge that assumption.

Visible buds were first recorded on the main stems. However, these buds did not develop normally and so were later ignored. Buds on the branches were subsequently recorded, although by this time (55 days from potting up) buds were already present on the branches of plants grown in the warm compartments under long days. Long days clearly hastened bud appearance as buds were not visible until 65 days from potting up in the warm compartment with a natural daylength. Temperature also had a significant effect; plants grown under a natural daylength had visible buds 19 days earlier when grown at a set-point of 15°C compared with 5°C. Supplementary lighting also hastened bud appearance by 7 days.

Overall plants grown in the warm temperature regime (15°C) flowered 38 days before those grown at a set-point of 5°C. This difference was greater (44 days) under long day conditions. Long days hastened flowering by an average of 8 days, although this response interacted with temperature. In the cool compartments long days only hastened flowering by 2 days, while in the warm compartments long days hastened flowering by 14 days. Supplementary lighting hastened flowering by 5 days.

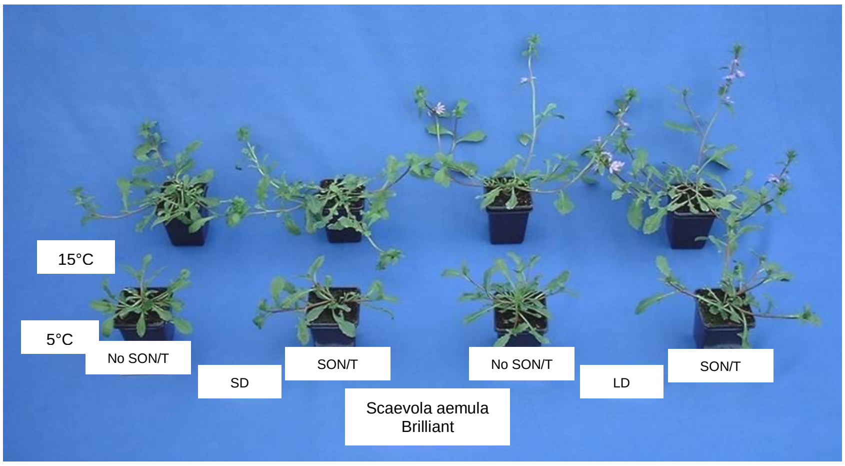


***Figure 55**. The effect of temperature, daylength and supplementary lighting on Scaevola cv. Brilliant. Photograph taken on 13/04/04.*

Both temperature and daylength had a significant effect on the length of the longest shoot at marketing. Long days increased the shoot length by 6 cm, while increasing the minimum temperature from 5°C to 15°C decreased the average shoot length at flowering by 6 cm.

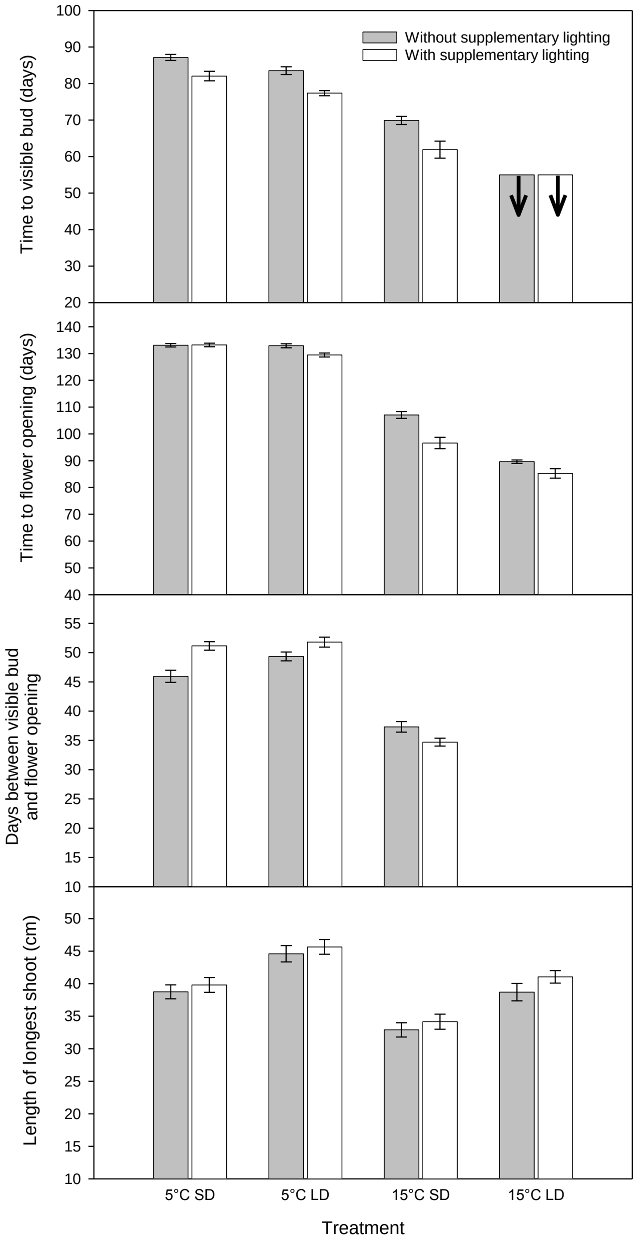


Figure 56. *The effect of temperature, daylength and supplementary lighting on Scaevola cv. Brilliant. Arrows indicate treatments which flowered before than 55 days from potting up.*

Verbena cv. New Ophelia

(Verbena x hybrida)

Verbena are a short lived perennials which originate from South America. Rooted cuttings were potted up on 22 January and then pinched on 6 February. The time of visible bud was affected by temperature, daylength and to a lesser degree supplementary lighting. Buds appeared 19 days earlier in the warm compartments and long days hastened bud appearance by 10 days. Supplementary lighting hastened bud appearance by 3 days on average.

The time from bud appearance to flower opening was also hastened by warmer temperatures and to a lesser degree long days. The combined effect was such that plants flowered 28 days earlier in the warmer compartments and long days hastened flower opening by 13 days. Supplementary lighting hastened flowering on average by just 2 days.

The lengths of the longest shoots were increased by 8 cm in the warm compartments at flowering. The use of tungsten lamps to provide long days also had a significant effect on shoot length; the average increase was 3 cm.

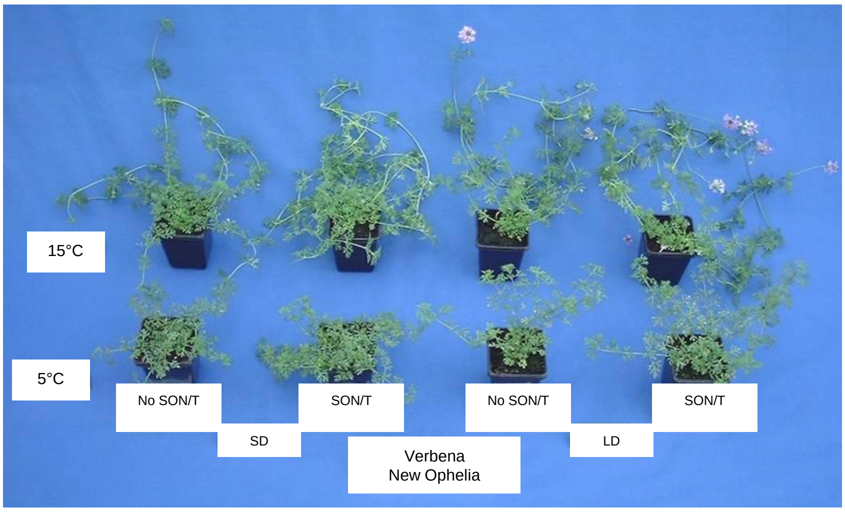


Figure 59. *The effect of temperature, daylength and supplementary lighting on Verbena cv. New Ophelia. Photograph taken on 13/04/04.*

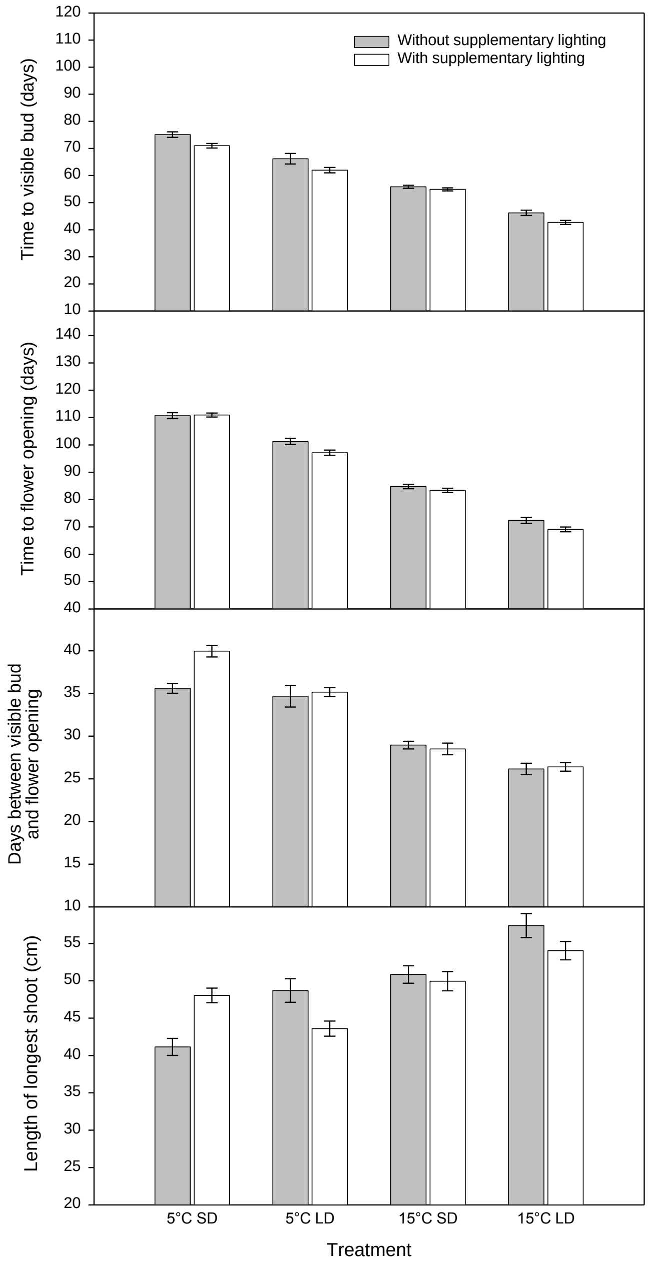


Figure 60. *The effect of temperature, daylength and supplementary lighting on Verbena cv. New Ophelia*

Verbena cv. Red Knight

(Verbena x hybrida)

Rooted cuttings were potted up on 22 January and then pinched on 6 February. The time of bud appearance was again hastened by warmer temperatures, although for Red Knight the difference between these compartments was just 8 days. Buds appeared much later in this cultivar, and these plants were less sensitive to daylength and more sensitive to supplementary lighting. Supplementary lighting hastened bud appearance by 8 days.

None of the treatments appeared to have a significant effect on the time from bud appearance to flower opening. Due to the effects of temperature and supplementary lighting on bud appearance, these treatments affected flowering time by 8 and 7 days, respectively.

The length of the longest shoot was increased by 11 cm as a result of increasing the temperature set-point from 5 to 15°C. Long day lighting increased shoot lengths by on average 9 cm, while supplementary lighting decreased the length by around 2 cm.

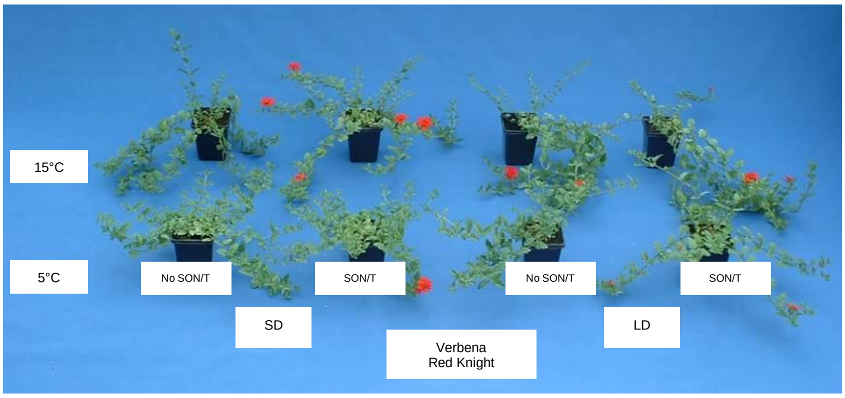


***Figure 61**. The effect of temperature, daylength and supplementary lighting on Verbena cv. Red Knight. Photograph taken on 25/05/04.*

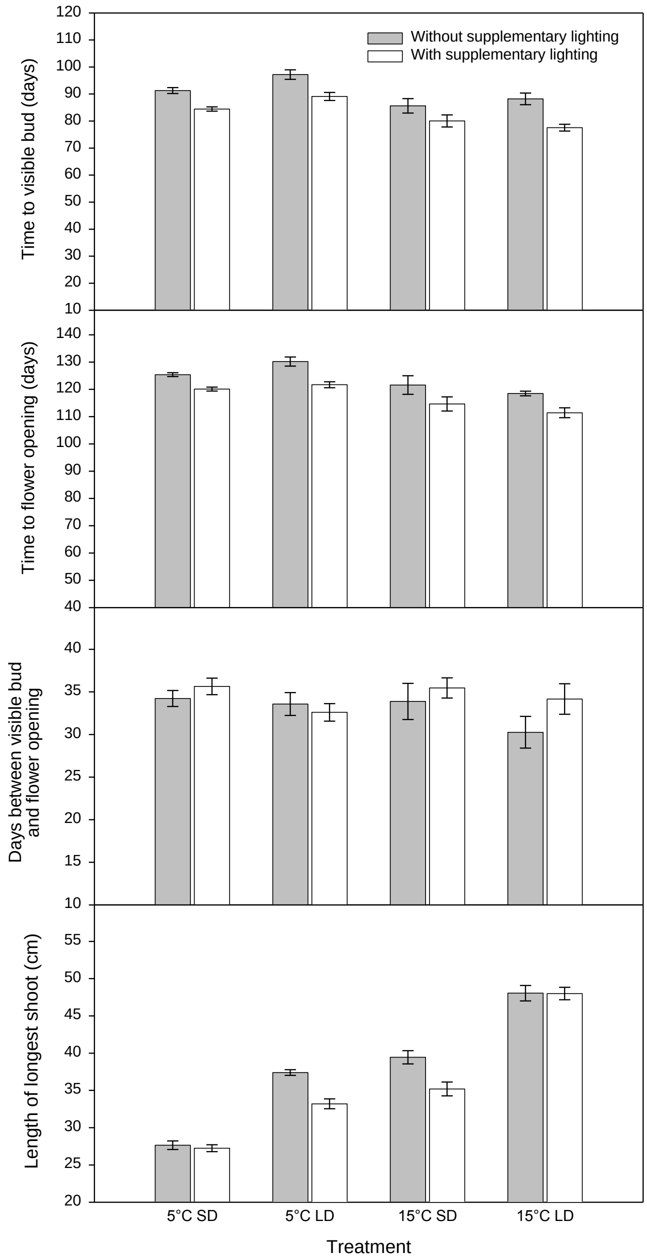


Figure 62. *The effect of temperature, daylength and supplementary lighting on Verbena cv. Red Knight*

2.4. Conclusions and general discussion

Warmer temperatures hastened flowering in 13 out of the 14 species examined (29 out of the 30 cultivars examined) (Table 2). Low temperatures only promoted flowering in Lotus. In nearly all of the cultivars studied, warmer temperatures hastened both the appearance of visible buds (Table 1) and the rate of flower development. Therefore, warmer temperatures could be used to hasten flowering of a wide range of patio plants. In most plants this also increased plant growth, although for some may have resulted in a slight loss of compactness. Growth regulators were not used in this trial, and may be used to elevate this problem. The main disadvantage of this strategy would be an increase in fuel costs if heating set-points were raised. An alternative and more cost effective solution would be to increase vent temperatures to maximise solar gain. However, this may result in increased humidity and so care should be taken to monitor the environment and introduce humidity control strategies.

Most of the species/cultivars were shown to be long day plants (Tables 1 and 2). The only plant in which flowering was hastened by short days was Lotus, while Argyranthemum, Bidens, Diascia, Felicia, and Verbena 'Red Knight' showed no significant response to daylength. The response to long day lighting was very pronounced in some species. For example, flowering was hastened by up to 40 days in Petunia (Surfinia). Therefore, there is considerable potential to use day extension or night break lighting to promote flowering, although crops grown slightly later in the year, when daylengths are increasing, may benefit less from this treatment. The fact that very few patio plants are short day plants means that lighting could be used on a combination of species to hasten flowering and make flowering time more predictable. The effect of daylength was often on reducing the time to visible bud; flower development was generally less sensitive to daylength. Therefore, long day lighting would not need to be applied over the whole life of the crop and could be applied for only a limited duration.

The running cost of long day lighting would be small, especially if cyclical night-break lighting were used for a limited period. The main costs would be for installation and maintenance. Long day lighting may increase stem elongation (Table 3). If tungsten

Table 1. *The effect of temperature, daylength and supplementary lighting on reducing the number of days to visible bud of a range of patio plants. For example, Antirrhinum 'Deep Purple' had visible buds 28 day sooner in the 15°C set-point compartments when compared with the 5°C compartments.*

Cultivar	Reduction in the time to visible bud (days)					
	Temperature		Daylength		Light integral	
	5°C	15°C	SD	LD	-SON/T	+SON/T
Antirrhinum Lum. Deep Purple		28		13[1]		5
Antirrhinum Lum. Harvest Red		22		10		
Argyranthemum Sultans Dream		9				5
Bacopa Snowflake						
Bidens aurea		7				
Diascia Joyce's Choice		25				7
Felicia Blue						4
Fuchsia Alice Hoffmann		37[3]		17[1]		
Fuchsia Barbara Windsor		25[3]		20[1]		3
Fuchsia Betty		13		10[1,5]		3
Fuchsia Dark Eyes		32		30[1,5]		
Fuchsia Deep Purple		29		24[5]		
Fuchsia Gene		25		12		3
Fuchsia Liza		27		24[5]		
Fuchsia Lyle's Unique		15[5]		19[5]		3
Fuchsia Marcia		22		5		
Fuchsia Maybe Baby		13		13[1,5]		
Fuchsia Nice 'n' Easy		28[3]		12[1]		5
Fuchsia Patio Princess		21		15		4[6]
Fuchsia Pink Marshmallow		24[3]		21[1]		
Fuchsia Pink Spangles		29[3]		20[1]		2
Lobelia Richardii		9[3]		27[1]		
Lobelia White Star		16		22		
Lotus Bertholetii	See text		See text			See text
Nemesia Blue Lagoon		9				6
Petunia Surfinia Blue		27[3]		46[1]		
Sanvitalia Aztec Gold		35[4]		14[2]		
Scaevola Brilliant		19		>10		7
Verbena New Ophelia		19		10		3
Verbena Red Knight		8				8

[1] Difference reduced if temperature reduced
[2] Difference reduced if temperature increased
[3] Difference reduced if SD
[4] Difference reduced if LD
[5] Difference reduced if pinched
[6] Difference reduced if in larger plug

Table 2. *The effect of temperature, daylength and supplementary lighting on reducing the number of days to flower opening of a range of patio plants. For example, Antirrhinum 'Deep Purple' had open flowers 30 day sooner in the 15°C set-point compartments when compared with the 5°C compartments.*

Cultivar	Reduction in the time to open flowers (days)					
	Temperature		Daylength		Light integral	
	5°C	15°C	SD	LD	-SON/T	+SON/T
Antirrhinum Lum. Deep Purple		30		13[1]		4
Antirrhinum Lum. Harvest Red		27		8		
Argyranthemum Sultans Dream		16				
Bacopa Snowflake		27		4		4
Bidens aurea		18				
Diascia Joyce's Choice		28				6
Felicia Blue		10				5
Fuchsia Alice Hoffmann		38[3]		16[1]		
Fuchsia Barbara Windsor		29[3]		21[1]		4
Fuchsia Betty		20		11[1,5]		
Fuchsia Dark Eyes		37		29[1,5]		
Fuchsia Deep Purple		30		18[5]		
Fuchsia Gene		31		11		4
Fuchsia Liza		33		25[5]		3
Fuchsia Lyle's Unique		20[5]		15[5]		3
Fuchsia Marcia		29				
Fuchsia Maybe Baby		22[5]		12[1,5]		
Fuchsia Nice 'n' Easy		33[3]		12[1]		5
Fuchsia Patio Princess		30[6]		12[1]		
Fuchsia Pink Marshmallow		23		21[1]		
Fuchsia Pink Spangles		31[3]		21[1]		2
Lobelia Richardii		27[3]		28[1]		
Lobelia White Star		26[3]		20[1]		2
Lotus Bertholetii	See text		See text			See text
Nemesia Blue Lagoon		22		2		6
Petunia Surfinia Blue		36[3]		40[1]		
Sanvitalia Aztec Gold		38[4]		12[2]		3
Scaevola Brilliant		44[3]		14[1]		5
Verbena New Ophelia		28		13		
Verbena Red Knight		8				7

[1] Difference reduced if temperature reduced
[2] Difference reduced if temperature increased
[5] Difference reduced if pinched
[4] Difference reduced if LD
[3] Difference reduced if SD
[6] Difference reduced if in larger plug

Table 3. *The effect of temperature, daylength and supplementary lighting on increasing the height/length of the longest shoot (in cm) at marketing of a range of patio plants. For example, Antirrhinum 'Deep Purple' plants were 5cm taller at marketing in the 5°C compartments when compared with the 15°C compartments.*

Cultivar	**Increase in plant height/shoot length (cm)**					
	Temperature		**Daylength**		**Light integral**	
	5°C	**15°C**	**SD**	**LD**	**-SON/T**	**+SON/T**
Antirrhinum Lum. Deep Purple	5			4		
Antirrhinum Lum. Harvest Red	3					
Argyranthemum Sultans Dream						
Bacopa Snowflake				3		2
Bidens aurea		14		6		8
Diascia Joyce's Choice						7[1]
Felicia Blue		5		6		
Fuchsia Alice Hoffmann				5		
Fuchsia Barbara Windsor		10		7		
Fuchsia Betty				6[2]		
Fuchsia Dark Eyes		3		3		
Fuchsia Deep Purple		9[2]				5
Fuchsia Gene		2				
Fuchsia Liza						
Fuchsia Lyle's Unique		11		3		
Fuchsia Marcia	2			4		
Fuchsia Maybe Baby		8		5		
Fuchsia Nice 'n' Easy		4		5		
Fuchsia Patio Princess		3		2		
Fuchsia Pink Marshmallow		5	6			
Fuchsia Pink Spangles		3		4		
Lobelia Richardii		9				
Lobelia White Star						
Lotus Bertholetii		20		13		
Nemesia Blue Lagoon		7		4		3
Petunia Surfinia Blue		18		5		
Sanvitalia Aztec Gold		5				
Scaevola Brilliant	6			6		
Verbena New Ophelia		8		3		
Verbena Red Knight		11		9	2	

[1] Difference reduced if temperature reduced
[2] Difference reduced if pinched

lamps were used commercially this might result in increased cost due to the use of growth regulators. However, the increased stem elongation was most likely a result of the red:far-red ratio of the tungsten lamps and not a response to long days *per see*. Therefore, it would be worth considering the use of other lamp types, for example, compact fluorescent lamps which have a different spectral output. One thing to bear in mind is that compact fluorescent lamps sold as equivalent in output to a 60 or 100W tungsten lamp are compared in relation to the human eye. They are not as bright as far as plants are concerned; light outputs expressed in terms of lux (brightness to the human eye) can be misleading!

A number of the species/cultivars examined showed an interaction between the responses to daylength and temperature. Often the response to long days was greater in the warmer temperature regime. Presumably this was due to warm temperatures hastening flowering and the fact that daylengths were increasing over the course of the experiment. Plants grown under lower temperatures were delayed and by the time that they were responsive to daylength the difference between the two daylength treatments had diminished. Similarly for some cultivars, the daylength response was reduced when plants were re-pinched. Presumably some of the floral material was removed and the natural daylength (in the SD treatments) had increased by the time new buds were initiated.

The response to supplementary lighting tended to be less pronounced compared with the effects of temperature and daylength. Supplementary lighting hastened flowering in around half of cultivars studied (Table 2). However, the maximum response was one week. Therefore, the potential for manipulation of flowering through supplementary lighting is limited unless they are used to create long days. The benefits would be greater for early crops. However, the costs of applying supplementary lighting are much greater than the use of low intensity long day lighting using compact fluorescent or tungsten bulbs. Although supplementary lighting may have an added benefit of increasing plant quality as a result of enhanced growth.

4. References

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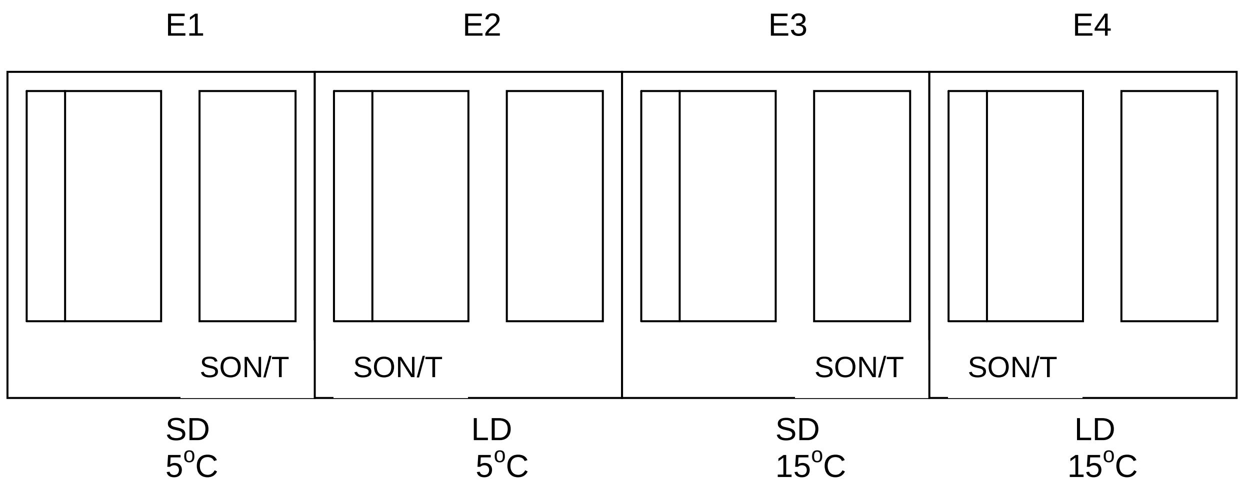
Appendix 1 – Experimental plan:



Appendix 2 – Pictures showing the 'visible bud' stages


Antirrinum - 1mm diameter


Argyranthemum – 2 mm diameter


Bacopa - 2 to 3 mm length


Bidens - 2 to 3 mm diameter


Diascia – 1 to 2 mm length


Felicia – 3 mm length


Fuchsia – 2 mm length


Lobelia – 1 mm length


Lotus – 1 mm height


Nemesia – 1 mm diameter


Petunia – 2mm length


Sanvitalia – 2 mm diameter


Scaevola – 1 to 2 mm diameter


Verbena – 2 mm length