FINAL REPORT

To:
Horticultural Development Council
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IMPROVED SCHEDULING OF VIOLAS AND PANSIES THROUGH THE USE OF NIGHT-BREAK LIGHTING

HDC Project PC 238

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Warwick HRI, Wellesbourne, Warwick, CV35 9EF

June 2007

Commercial - In Confidence

Grower Summary

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Final report 2007

Project title:	Improved scheduling of violas and pansies through the use of night-break lighting
Project number:	PC 238
Project leader:	Dr Steve Adams
Final report:	June 2007
Key workers:	Dr Steve Adams – Project leader Dr Veronica Valdes – Experimental co-ordinator Angela Hambidge – Data collection
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Signed on behalf of: **Warwick HRI**

Signature: ..………………………………………. *Date:*………………………………….

Name: Professor Simon Bright
Director and Head of Department

CONTENTS

GROWER SUMMARY

Headline

It is not feasible to use night-break lighting with fluorescent lamps to improve the scheduling of violas and pansies. While it is possible that all of the cultivars examined are practically day-neutral, the lack of response may have been due to the quality of light from the fluorescent lamps.

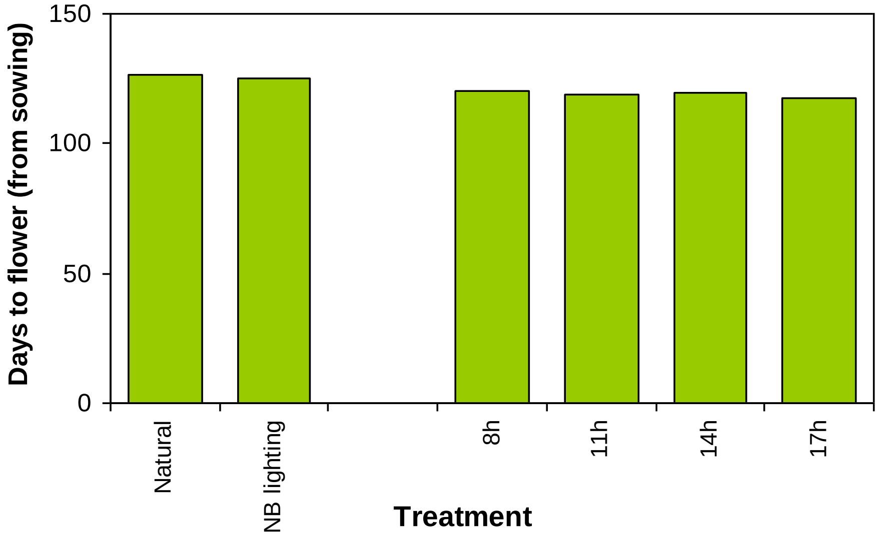
Background and expected deliverables

The flowering of modern varieties of pansy and viola using standard production methods leaves short, but important, gaps in the potential sales periods when the plants are of saleable size but have little or no flower. These gaps do not occur at the same time in all parts of the country as the sales periods are influenced by weather conditions. This shows the need for programmeability in this crop which will require the application of techniques already researched, but not yet commercially applied for the control of flowering.

While light integral appears to have the biggest impact on the time to flowering of pansies (Adams *et al*., 1997), the cost of supplementary lighting excludes its use as a tool for the commercial scheduling of pansies and violas. Similarly, temperature affects flowering time, but the potential to manipulate it to control flowering is limited as crops are grown cool to reduce energy costs and to maximise quality (Adams *et al*., 1996). While modern winter flowering pansies are sometimes assumed to be day-neutral, pansies have been shown in the past to be quantitative long-day plants (Hughes and Cockshull 1966; Adams *et al*., 1997; Runkle and Heins, 2003). This means that while they will flower under short days in winter, flowering is hastened under long-day conditions. While this has been known for some time it has not been exploited to any extent by the industry. Furthermore, there is little information on the response of violas to daylength.

Summary of the project and main conclusions

The effects of daylength on flowering time of violas were examined in year 1. Seeds from the Sorbet and Butterfly series (6 colours from each) were sown by a commercial propagator in weeks 31 and 33 for autumn and weeks 38, 40 and 42 for spring crops. When the plugs were marketable they were transported to Warwick HRI where they were potted up into 6 packs and grown on under a range of fixed daylengths (8, 11, 14 and 17 hours), and with and without 3-hour night-break lighting. Surprisingly, there was little evidence of any effects of daylength in either of the experiments. This was consistent across all of the cultivars examined suggesting that either viola are day-neutral or that the plants had already initiated flowers while in plugs.



The effect of daylength on time to flowering averaged across all batches and cultivars in Year 1.

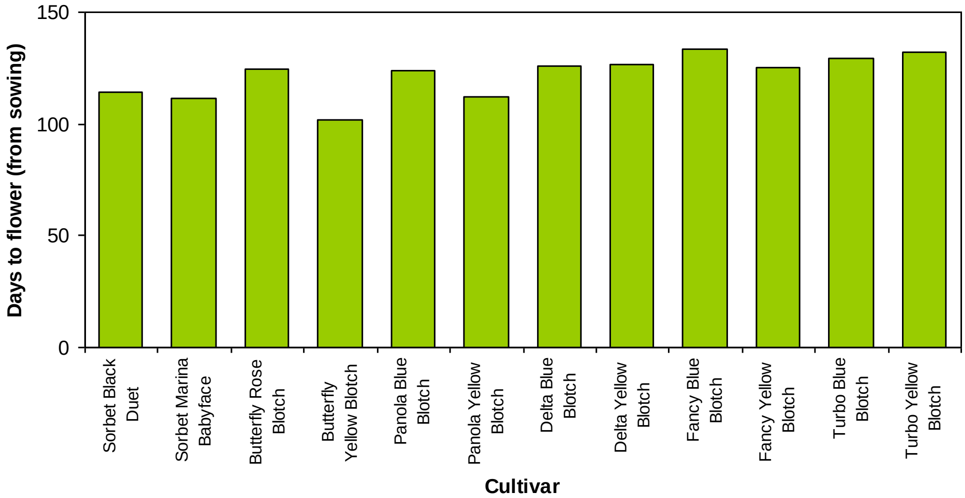
In year 2, seed was sown and germinated at Warwick HRI and daylength was manipulated for both plugs and packs. Furthermore, a number of pansy cultivars were incorporated into the trial (see figures for details). Seeds were again sown in weeks 31 and 33 for autumn and weeks 38, 40 and 42 for spring crops.

Although crops are unlikely to be grown under fixed daylengths commercially, an experiment using photoperiod chambers was used to quantify the flowering responses of the different cultivars to daylength. Two identical glasshouse compartments, each containing a suite of four photoperiod chambers, were used to provide daylengths of 8, 11, 14 and 17 hours. A second experiment compared a crop grown under a natural (changing) daylength with one where night-break lighting

(10:30 to 01:30 GMT) was used to simulate long days for plugs, packs or both. This was carried out to quantify the potential commercial benefits of manipulating daylength.

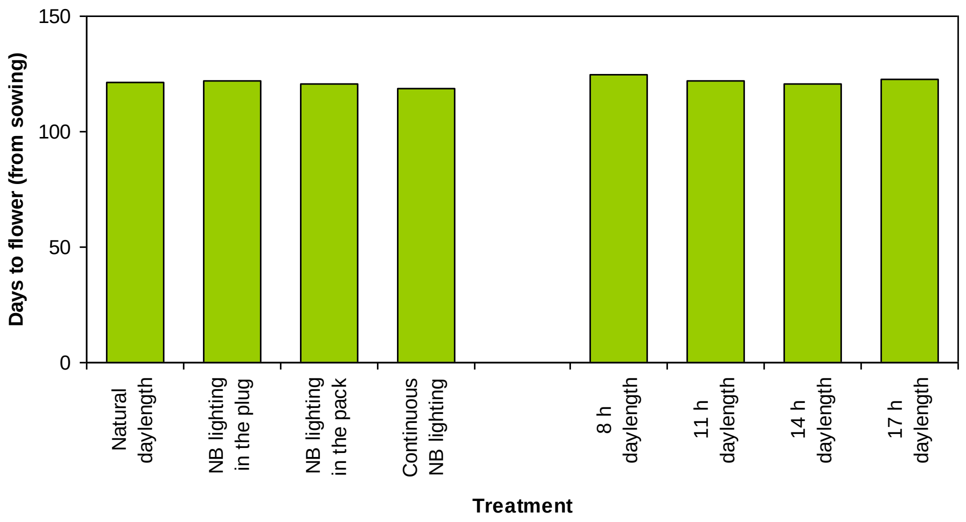
Photograph showing the plants on the photoperiod trolleys to the left and plants grown on the floor with night-break lighting to the right.

The biggest impact on the time to flower was the sowing date. As anticipated, the first two batches flowered quickly in time for the autumn market, while the last three batches over-wintered and flowered in spring. As one might expect there were also cultivar differences within a series.



The effect of cultivar on time to flowering averaged across all batches and treatments.

Surprisingly, there was little evidence of any effects of fixed daylength treatments. In the second experiment which used night-break lighting, there was a small, but nonetheless significant, effect of lighting. However, the hastening of flowering was insufficient to justify commercial exploitation; plants grown with night-break lighting flowered on average 3 days before those grown under ambient lighting, this was principally due to the effect of lighting after potting on into packs.

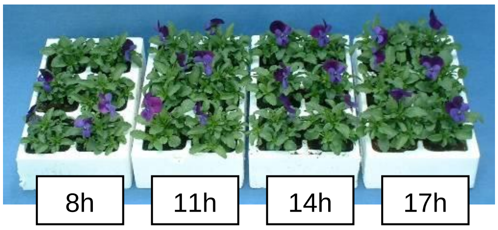


The effect of daylength on time to flowering averaged across all batches and cultivars

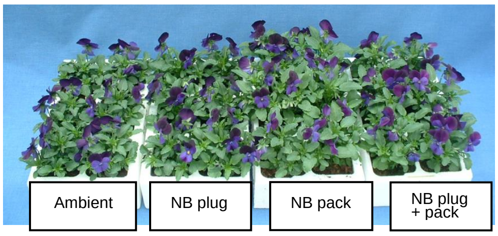
When packs were at the marketable stage (at least one open flower per plant), three plants of Butterfly Yellow Blotch and three plants of Delta Yellow Blotch were sampled from each pack to record plant quality. There was no significant effect of the long-day or night-break lighting treatments on shoot fresh weight. While, for these cultivars, there was no significant difference in the height of the plants grown on under different fixed daylengths, the plants grown on the floor with night-break lighting were around 0.4cm taller than those grown under a natural daylength. Having reached the marketable stage, packs were left for a further two weeks and the number of open flowers per pack were recorded. Night-break lighting increased flower numbers slightly, from 3.4 to 3.7 per plant.

The year 2 trial showed no significant effect of day-extension lighting, and only a very small effect of night-break lighting. Plants were lit throughout production and so the results are clearly not due to the treatments being applied too late in production. Therefore, the results would tend to suggest that the modern cultivars examined are indeed day-neutral. However, it is possible that the lack of response to lighting could have been due to light quality. Fluorescent lamps were chosen for the lighting treatments to minimise the stretching that often occurs with tungsten lamps, although the light quality from these lamps may have been inappropriate to stimulate a long-day response.

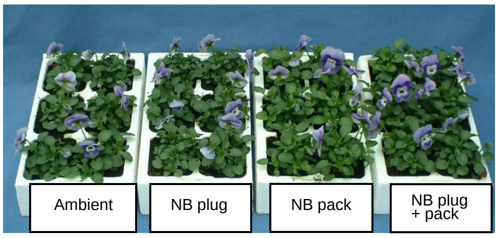
Photographs showing the effects of the fixed daylength and night-break lighting treatments (sown week 40 or 42).

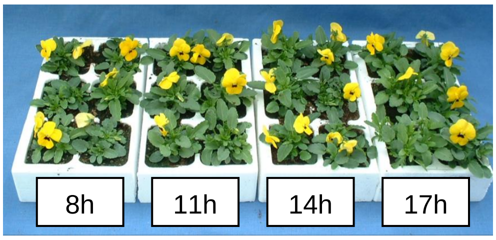


Sorbet Black Duet

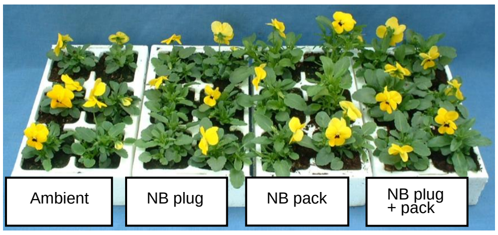


Sorbet Marina Babyface

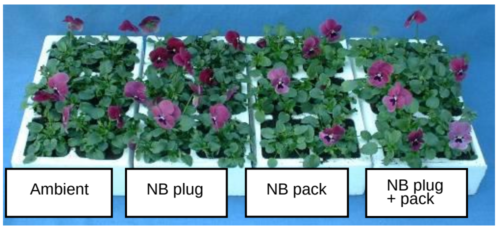


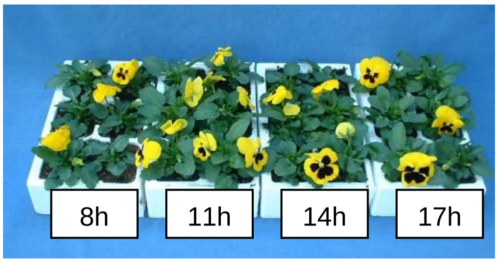


Butterfly Yellow Blotch

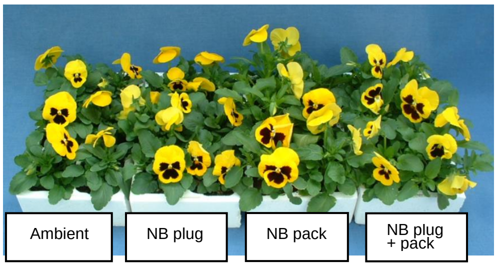


Butterfly Rose Blotch

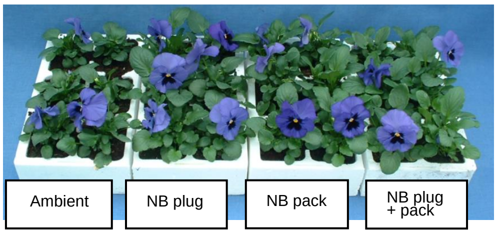


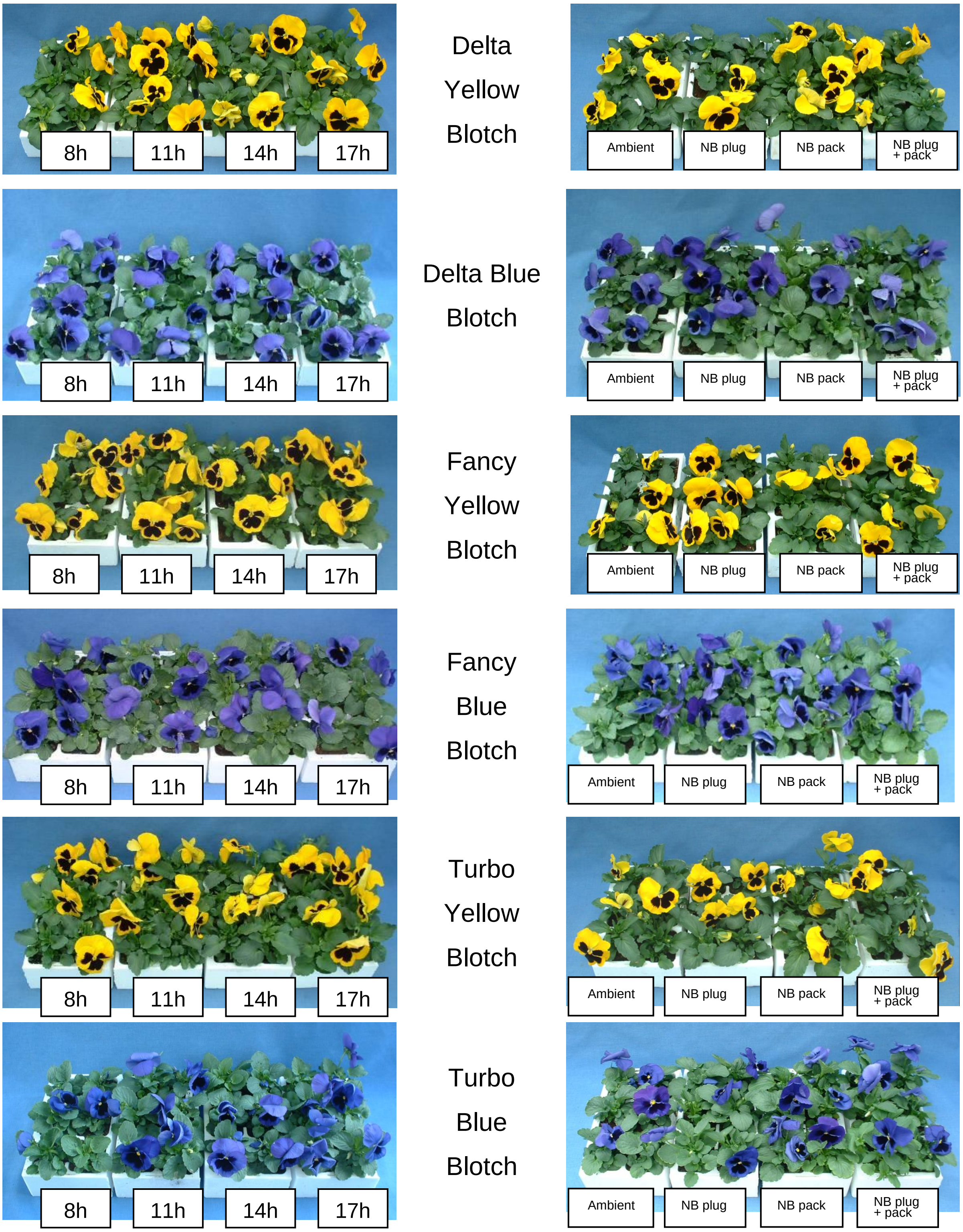


Panola Yellow Blotch



Panola Blue Blotch





Great care is needed when switching from tungsten to fluorescent lamps for night-break lighting. A 15W compact fluorescent lamp sold as having an equivalent output to a 60W tungsten bulb will not be comparable for horticultural purposes as the manufacturers do their conversion in lux, which is related to what the human eye perceives, rather than PAR (photosynthetically active radiation; 400 – 700 nm). The general rule of thumb for short-day species is that providing that the PAR output is comparable, the lamps should be suitable for night-break lighting. These results question whether that assumption is correct. Indeed other trials have shown little or no response to night-break lighting with fluorescent lamps for species known to be long-day plants. Given the increasing popularity of compact fluorescent lamps and the pressure to switch to these to save energy, it is important that further work is done to investigate their suitability for day-extension and night-break lighting particularly for long-day species.

Financial benefits

The use of night-break lighting with fluorescent lamps had only a very small impact on flowering time. The benefits were insufficient to justify the capital or electricity costs of the lamps.

Action points for growers

The results do not indicate the need to change current commercial practice for the production of pansies or violas. However, the results question the suitability of fluorescent lamps for day-extension or night-break lighting. Care should therefore be taken if you are considering switching from tungsten bulbs.

Science section

Introduction

The flowering of modern varieties of pansy and viola using standard production methods leaves short, but important, gaps in the potential sales periods when the plants are of saleable size but have little or no flower. These gaps do not occur at the same time in all parts of the country as the sales periods are influenced by weather conditions. For example, growers in the south east report a period in late October/early November when it is hard to produce a marketable product in flower, whereas growers further north appear to have greater difficulty in early spring. This shows the need for programmeability in this crop which will require the application of techniques already researched, but not yet commercially applied for the control of flowering.

While light integral appears to have the biggest impact on the time to flowering of pansies (Adams *et al*., 1997), the cost of supplementary lighting excludes its use as a tool for the commercial scheduling of pansies and violas. Similarly, temperature affects flowering time, but the potential to manipulate it to control flowering is limited as crops are grown cool to reduce energy costs and to maximise quality (Adams *et al*., 1996). While modern winter flowering pansies are sometimes assumed to be day-neutral, pansies have been shown in the past to be quantitative long-day plants (Hughes and Cockshull 1966; Adams *et al*., 1997; Runkle and Heins, 2003). This means that while they will flower under short days in winter, flowering is hastened under long-day conditions. While this has been known for some time it has not been exploited to any extent by the industry.

To enable the exploitation of long-day or night-break lighting, popular varieties need to be screened for their response to daylength. In year 1 of the project we showed that daylength had little effect on the time of flowering of violas from the Sorbet and Butterfly series when treatments were applied after plugs were potted up. Therefore the work in year 2 aimed to investigate the effect of lighting at the plug stage and also incorporated pansies.

Materials and methods

The experiments examined the effects of daylength on the flowering time of pansies and violas. Six series were used, with two colours from each series (Table 1). Seeds were sown into 216 trays which divide into quarters (cell size similar to a standard 240 tray) containing seed compost obtained from W.J. Findon & Son. Seeds were sown in weeks 31 and 33 for autumn and weeks 38, 40 and 42 for spring crops (Table 2). Trays were covered with vermiculite, watered and were germinated at 17°C in the dark. After 5 days the trays were moved to a glasshouse compartment set to provide an 8 hour day. The trays remained in this compartment for 6 days during which time the temperature set-point was lowered from 16 to 12°C (vent +2°C) and the threshold for the shade screen was increased from 200 W/m^2 to 400 W/m^2. Seedlings were subsequently moved to the experimental treatments where they were grown in glasshouse compartments set to provide only frost protection (heating set point 3°C, venting at 5°C). For the plugs Vitafeed 101 (0.33g/l) was used as a background feed and Vitafeed 111 (0.67g/l) was used once a week.

***Table 1**. The series/colours included in the trial.*

	Series	Colour	Seed source
Viola	Sorbet	Black Duet	BallColegrave
		Marina Babyface	
	Butterfly	Yellow Blotch	Rudy Raes
		Rose Blotch	
Pansy	Panola	Yellow Blotch	BallColegrave
		Blue Blotch	
	Delta	Yellow Blotch	Syngenta Seeds
		Blue Blotch	
	Fancy	Yellow Blotch	Moles Seeds
		Blue Blotch	
	Turbo	Yellow Blotch	BallColegrave
		Blue Blotch	

When the plugs were marketable they were potted up into polystyrene 6 packs containing Vapogro Autumn Bedding compost (100% peat, pH of 5.5, wetting agents, P.G. Mix 14-16-18 @1.5Kg/m^3 and Ironite @1.5Kg/m^3). Plants were watered overhead as necessary. After the first 3 weeks from potting up potassium nitrate was used approximately weekly (weather dependent) at a rate of 1g/l.

Table 2. *Dates when batches of plants were sown and when the plugs were judged to be marketable and were transplanted into six packs.*

Sowing		Transplanting	
Week	Date	Week	Date
31	3 Aug	36	5 Sep
33	17 Aug	38	19 Sep
38	21 Sep	46	17 Nov
40	5 Oct	48	27 Nov
42	19 Oct	51	19 Dec

Experimental treatments

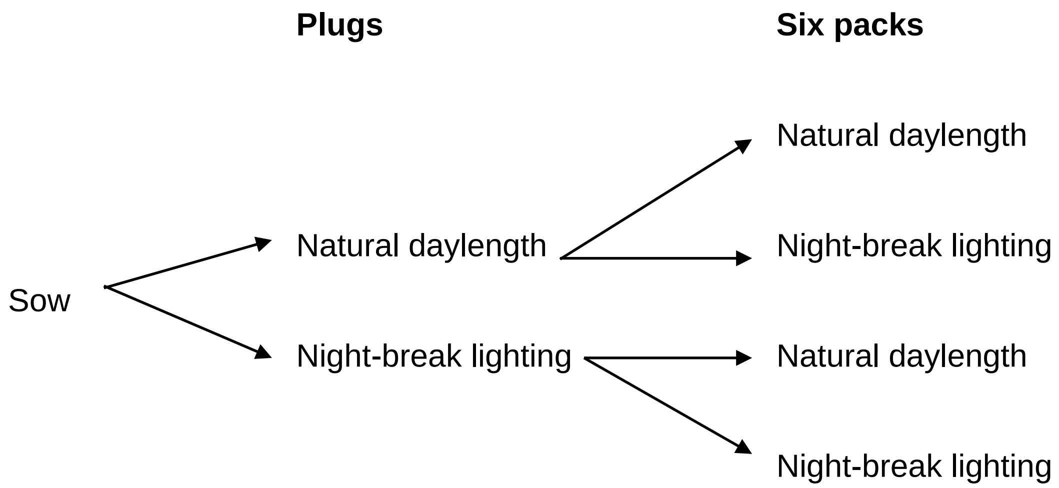
Experiment 1 – fixed daylengths

Although crops are unlikely to be grown under fixed daylengths commercially, an experiment using photoperiod chambers was carried out to quantify the flowering responses of the different cultivars to daylength. Two identical glasshouse compartments containing suites of four photoperiod chambers were used. Plants were grown on automated trolleys (1.7m^2) which receive natural daylight for 8 hours per day. At 16:00 h (GMT) each day the trolleys were moved into the light-tight chambers where they remained until 08:00 h the following day. Long days were provided with low intensity day-extension lighting (~3.0 µmol/m^2/s) using fluorescent lamps. The facility was used to provide daylengths of 8, 11, 14 and 17 hours (see appendix 1 for an experimental plan). As long days were provided with low intensity lighting, all these treatments received a similar light integral. The chambers were ventilated at night to minimise any temperature lift due to the lamps. There was one pack of each series/colour/batch on each trolley with two replicate trolleys (one in each glasshouse compartment) for any given photoperiod treatment.

Experiment 2 – natural daylengths and night-break lighting

A second experiment compared a crop grown under a natural (changing) daylength with one where night-break lighting was used to simulate long days in either plugs or packs or both. This was carried out to quantify the potential commercial benefits of manipulating daylength.

Plants were grown on the floor in the two glasshouse compartments used for experiment 1. In one compartment plants were grown under a natural daylength, while in the other compartment a three hour night-break lighting treatment (10:30 to 01:30 GMT) was applied using compact florescent lamps (~2.5 µmol/m^2/s). So as to avoid light pollution from the lit treatment the two glasshouse compartments were not adjacent. Plants were moved between compartments so that they were grown with and without night-break lighting both during plug production and after potting on into packs, giving 4 treatment combinations with 2 replicate plots of each.



Plant and environmental records

The day that the first flower of each plant opened was recorded. When packs were marketable (at least one open flower per plant), three plants of Butterfly Yellow Blotch and three plants of Delta Yellow Blotch were sampled per pack to record plant quality (shoot fresh weight and plant height). The remaining plants were left for a further two weeks and the numbers of open flowers per pack were recorded to indicate whether the treatments affected flower numbers.

Environmental data were recorded via the climate computer (Priva Integro) and a number of independent sensors linked to Orchestrator software and data-loggers (DL2, Delta-T Devices Ltd). Light sensors (quantum sensors and Kipp Solarimeters) were positioned in the compartments including below the night-break lighting treatment.

Figure 1. *Photograph of the experimental facilities showing the layout of the experiment with the plants on the photoperiod trolleys to the left and plants grown on the floor with night-break lighting to the right (see appendix 1 for an experimental plan).*

P&D control and physiological disorders

Plants were sprayed with Alliete (5g/l) and Amistar (1ml/l) after transplanting as a preventative for Downy mildew. Due to some caterpillar damage, Toppel 10 was applied (0.62 ml/l) in September and again in November. Some leaves showed a leaf edge scorch which might have been due to Botrytis and so a couple of Rovral sprays (1 g/l) were used in September. Furthermore, due to black spot a spray programme involving Bavistin (0.5g/l) and Amistar (1ml/l) was used. *Amblyseius cucumeris* was introduced regularly as a precaution against thrips and *Steinernema feltiae* were introduced for the control of scarid flies. A few plants showed leaf distortion and mottling, data from these plants were excluded from the analyses.

Results

Environmental conditions achieved

The two glasshouse compartments had very similar environments. The average temperature over the course of the whole experiment was 12.6°C and the relative humidity averaged 70%. Due to external conditions the glasshouse temperatures decreased through autumn into winter and then began to increase again towards the end of the experiment (Figure 2). The changes in light levels (PPFD) and natural daylength over the course of the experiment are shown in Figure 3.

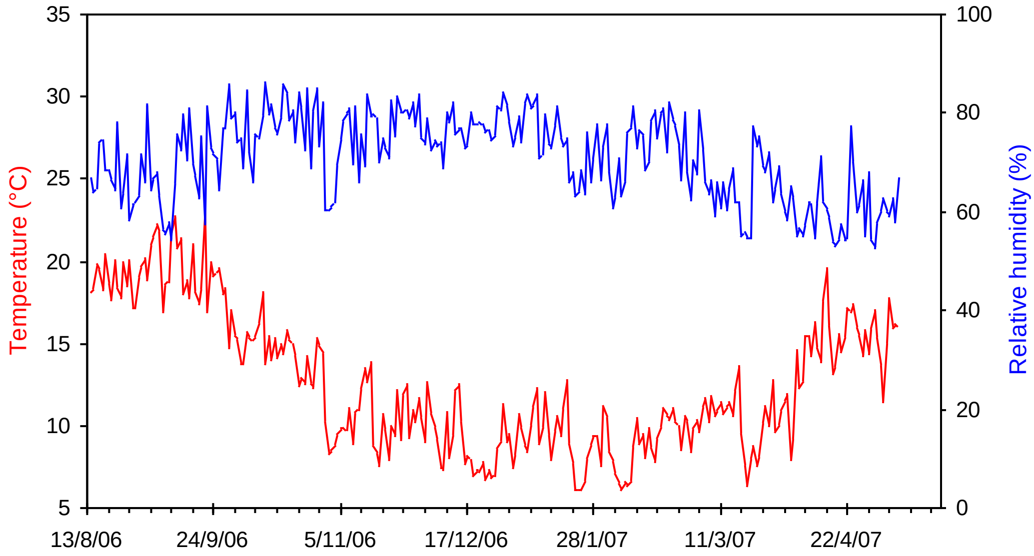


Figure 2. *Mean diurnal values of air temperature and relative humidity recorded in the experimental glasshouses over the course of the experiment.*

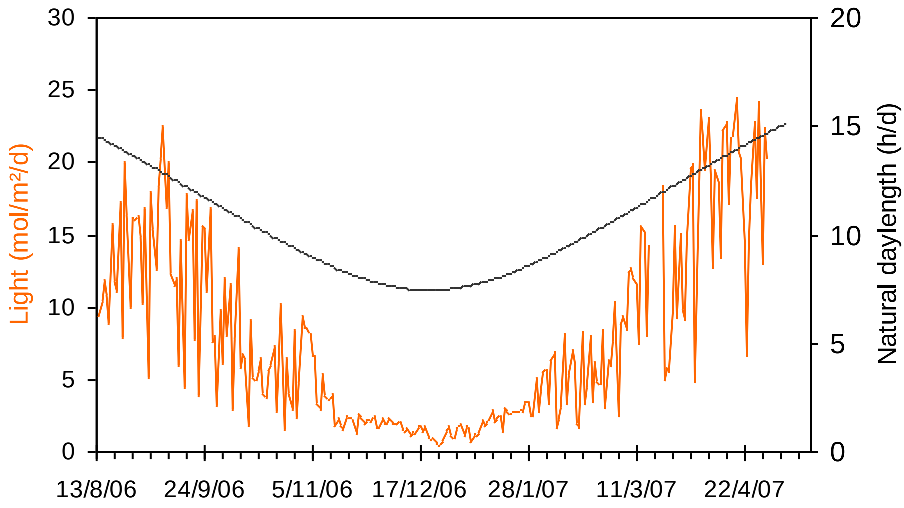


Figure 3. *Daily light levels (PPFD from sunrise to sunset) measured at plant height in the night-break lighting treatment together with the natural photoperiod which the plants without night-break lighting would have experienced.*

Flowering time

The biggest impact on the flowering time (time from sowing to first open flower) was the sowing date (*P*<0.001). As anticipated, the first two batches flowered quickly in time for the autumn market while the last three batches over-wintered and flowered in spring (Figure 4).

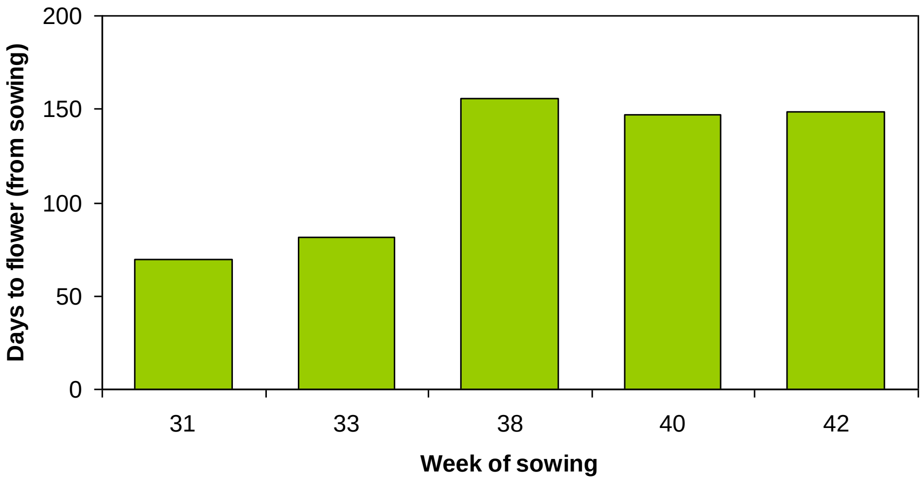


Figure 4. *The effect of sowing date on time to flowering averaged across all cultivars (SED = 0.616; 622 d.f.).*

As one might expect there were also cultivar differences (*P*<0.001). Butterfly Yellow Blotch consistently flowered first, followed by Sorbet Marina Babyface, Panola Yellow Blotch and Sorbet Black Duet. All of the pansy cultivars flowered on average within 5 days of one another.

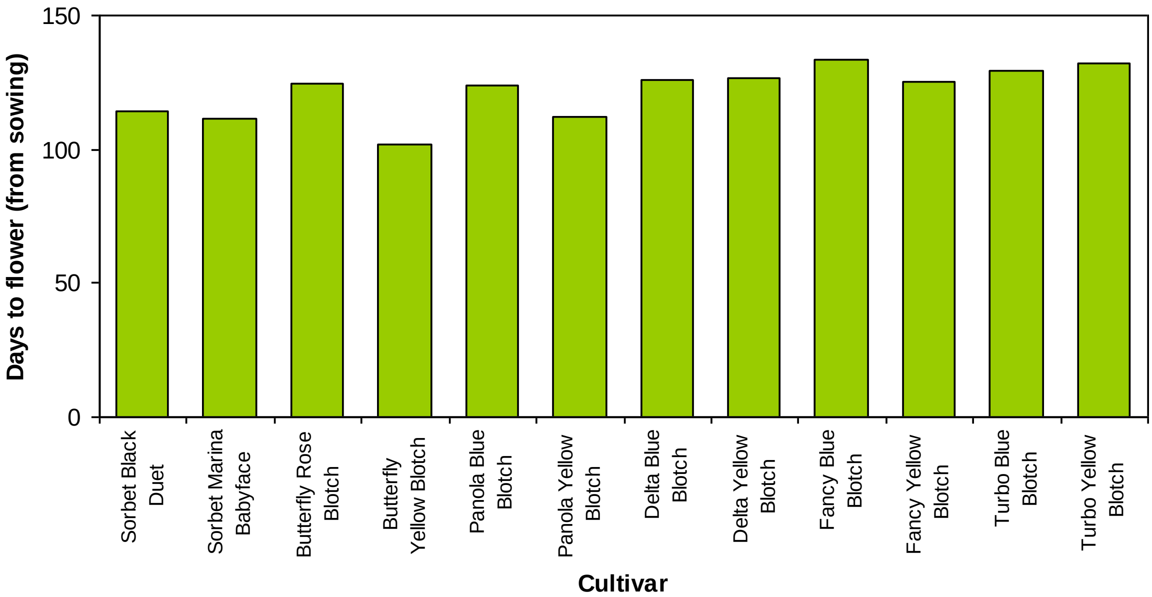


Figure 5. *The effect of cultivar on time to flowering averaged across all batches (SED = 0.954; 622 d.f.).*

There were differences in the flowering time for the two experiments (*P*<0.001); the week 31 crop flowered around 19 days earlier on the floor (experiment 2) when compared to the photoperiod trolleys (experiment 1), the difference was reduced to 8 days for the week 33 crop. The three subsequent crops flowered 6 to 9 days later on the floor when compared with the photoperiod trolleys. This was presumably because the plants on the floor received more light in autumn due to the fact that they received a natural daylength (the plants on the trolleys did not get any sunlight from 16:00 to 08:00 GMT). However, over the winter months the effect of the daylength would have been small and they would have been shaded more than the trolleys when the solar angle was low.

As in the year 1 experiment the effects of photoperiod were very small despite the fact that treatments were applied to both plugs and packs, and pansy varieties were included. In experiment 1, where daylengths of 8 to 17 hours were created using low intensity day-extension lighting with fluorescent lamps, there was little evidence to suggest that long days hastened flowering (Figures 6 and 7). Furthermore, there was no significant interaction between cultivar and the response to daylength suggesting that all of the varieties responded in a similar way.

In the second experiment there was a small, but nonetheless significant, effect of night-break lighting. However, the hastening of flowering was insufficient to justify commercial exploitation; plants grown with night-break lighting flowered on average 3 days before those grown under ambient lighting (Figures 6 and 8). This was principally due to the effect of lighting after potting on into packs. The plants might have been less sensitive to daylength in the plugs due to the fact that they were juvenile for a large part of this time. Furthermore, the natural daylength was longer at the beginning of the experiment (Figure 3), particularly for the early batches, which would have minimised the treatment effect.

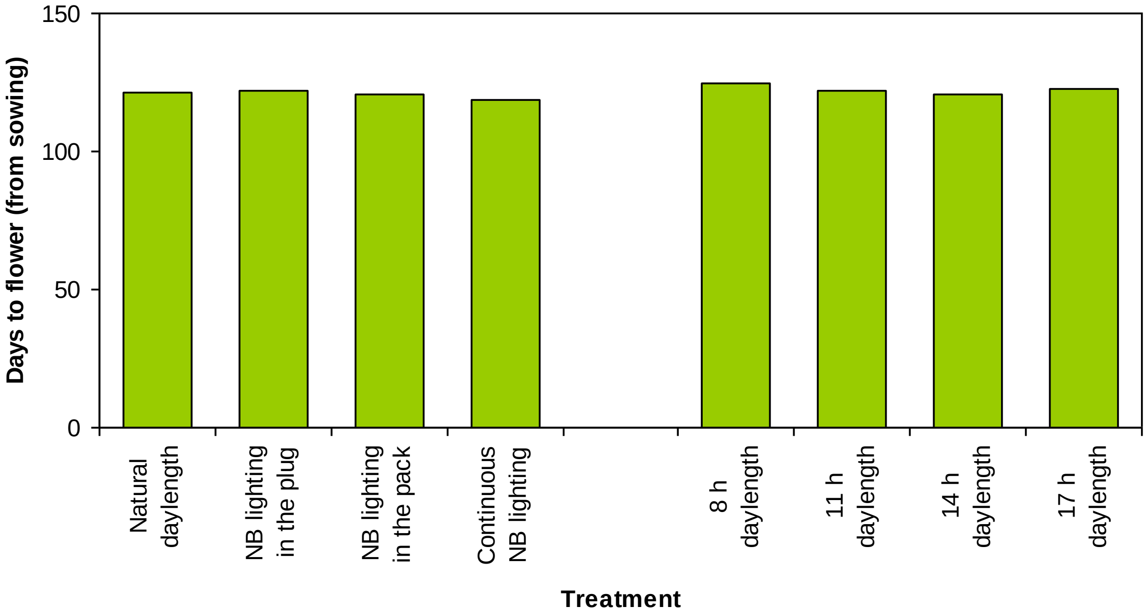
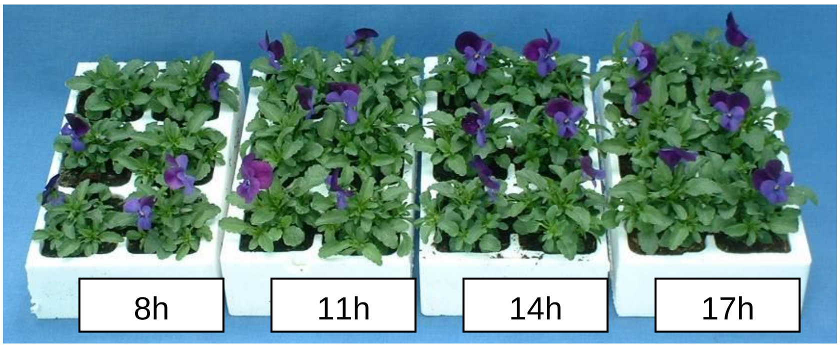


Figure 6. *The effect of daylength on time to flowering averaged across all batches and cultivars (SED for comparison of NB lighting treatments (expt. 2) = 0.672; 191 d.f., SED for comparison of fixed photoperiods (expt. 1) = 0.927; 239 d.f.).*

Figure 7. *Photographs showing the effects of the fixed daylength treatments (sown week 40 or 42).*



Sorbet Black Duet

Sorbet Marina Babyface

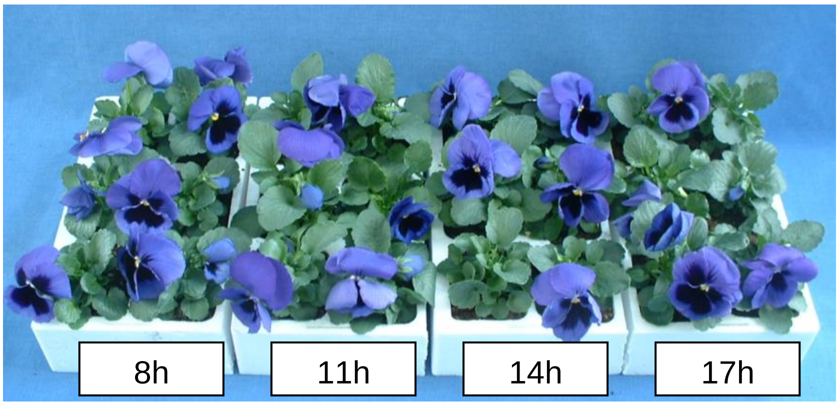
Butterfly Yellow Blotch

Butterfly Rose Blotch

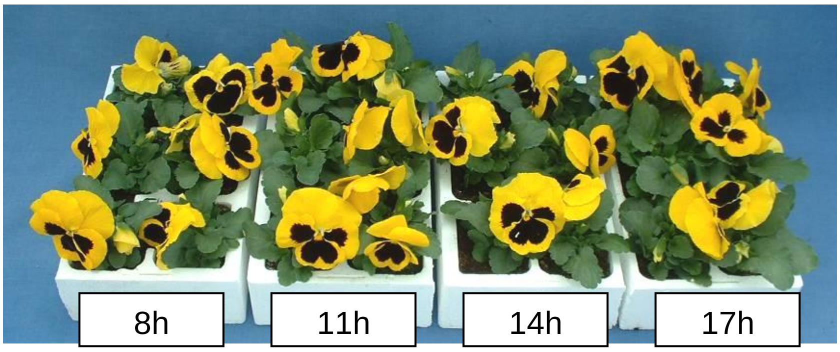
Panola
Yellow Blotch

Panola Blue
Blotch

Delta Yellow
Blotch



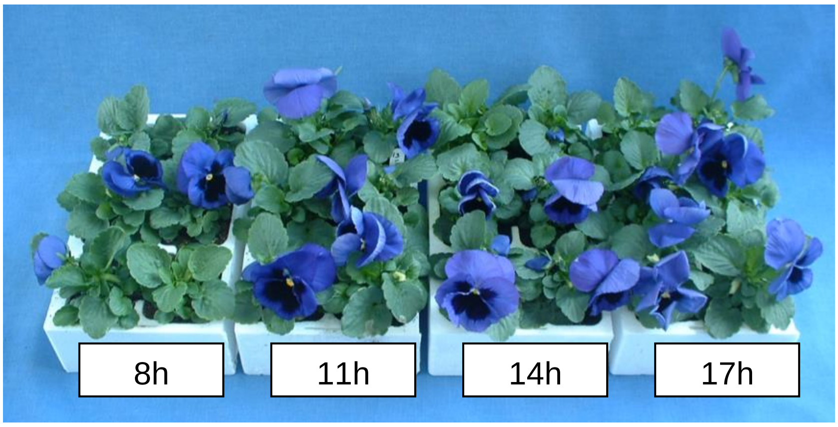
Delta Blue
Blotch



Fancy Yellow Blotch

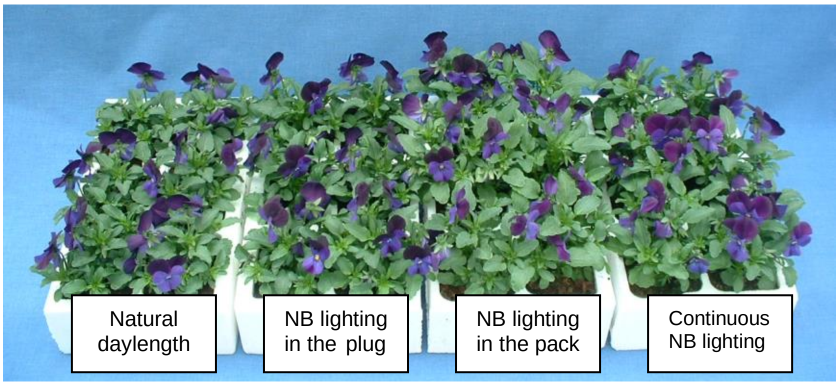
Fancy Blue Blotch

Turbo Yellow Blotch

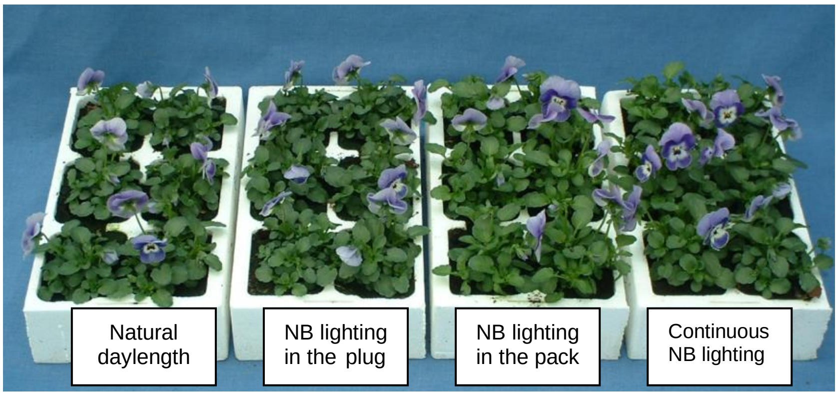


Turbo Blue Blotch

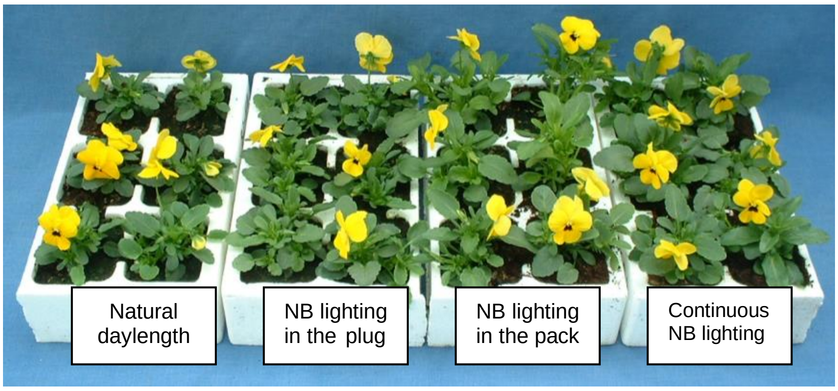
Figure 8. *Photographs showing the effects of the night-break lighting (sown week 40 or 42).*



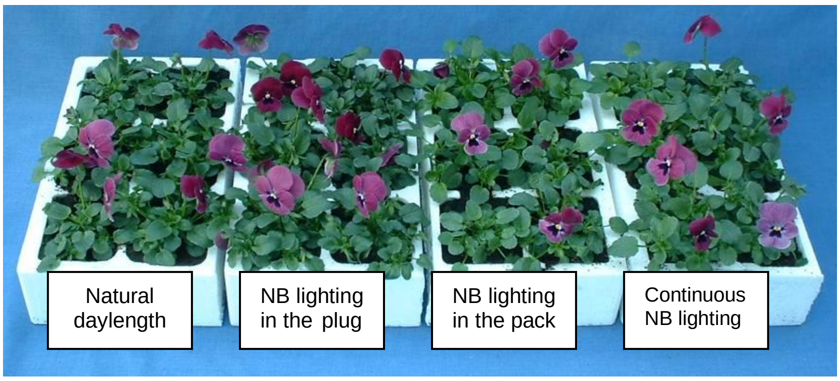
Sorbet Black Duet



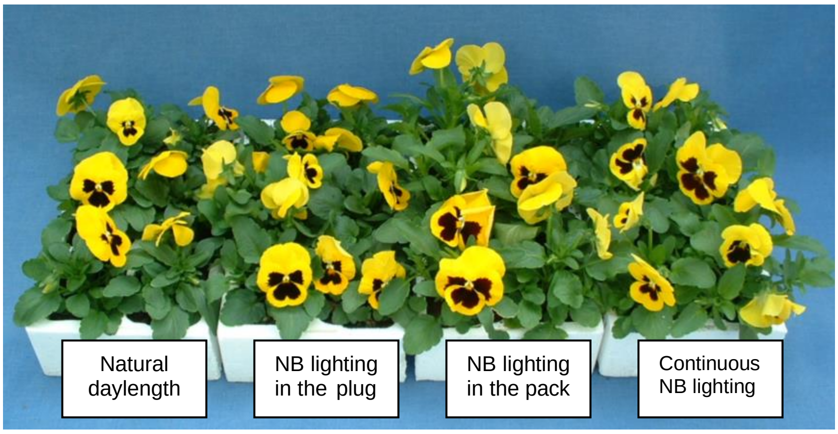
Sorbet Marina Babyface



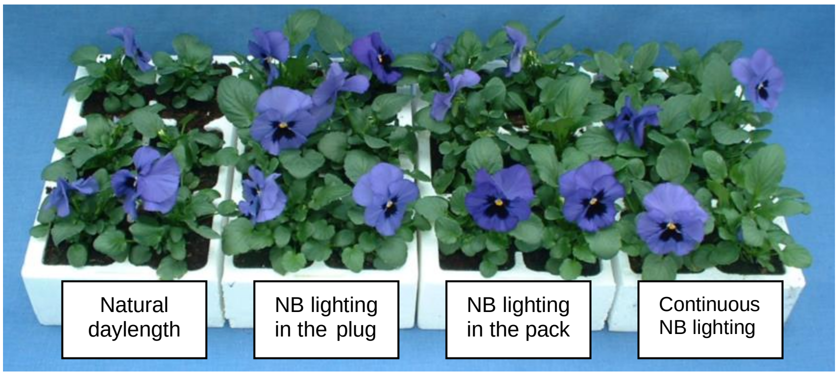
Butterfly Yellow Blotch



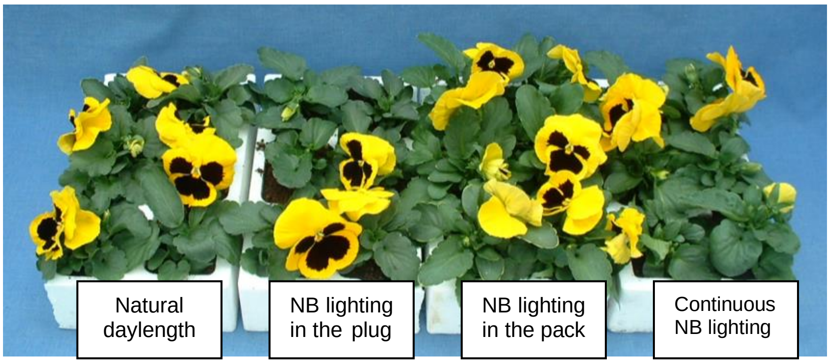
Butterfly Rose Blotch



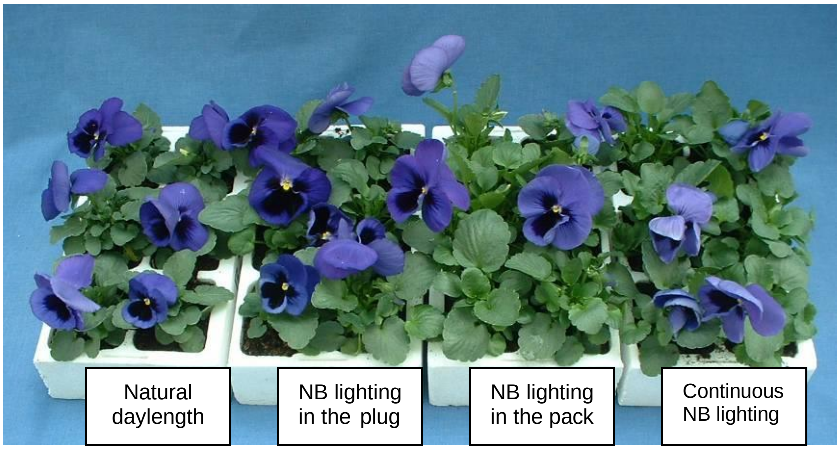
Panola Yellow Blotch



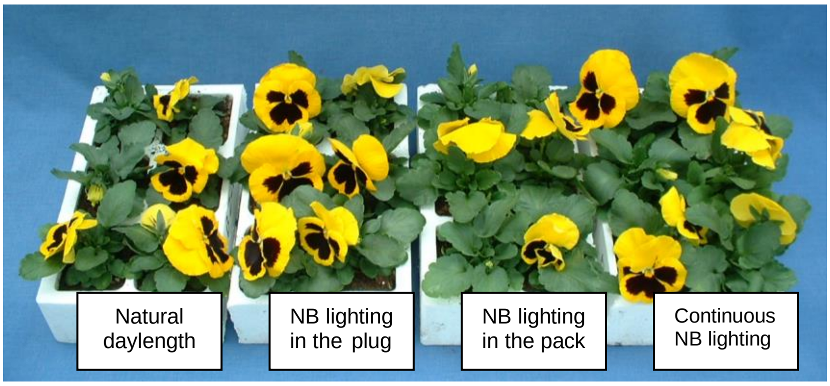
Panola Blue Blotch



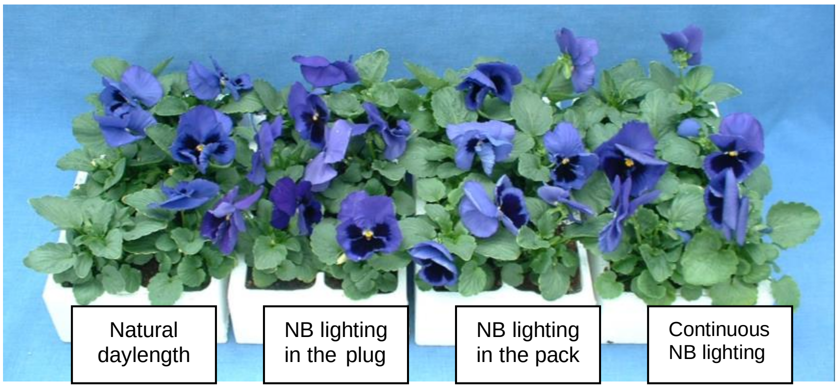
Delta Yellow Blotch



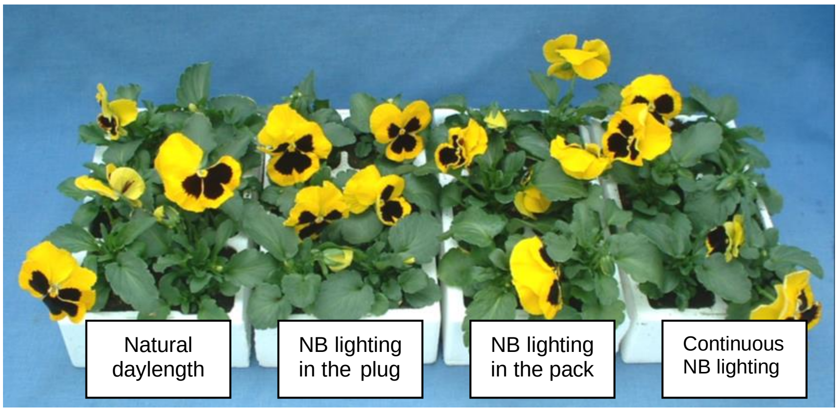
Delta Blue Blotch



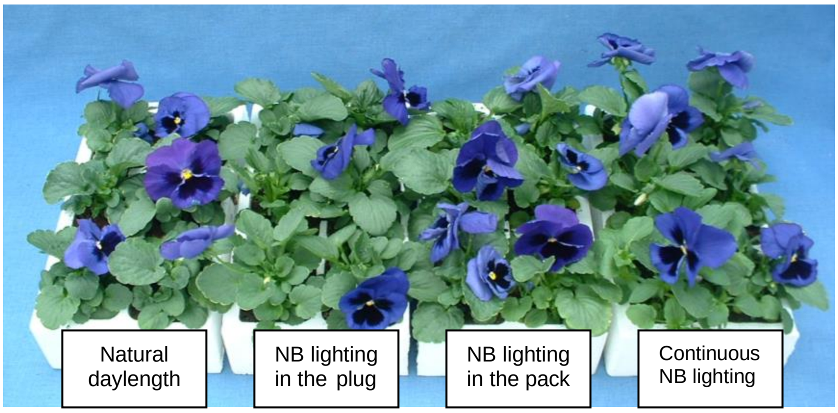
Fancy Yellow Blotch



Fancy Blue Blotch



Turbo Yellow Blotch



Turbo Blue Blotch

Plant fresh weight and height

When packs were at the marketable stage (at least one open flower per plant), three plants of Butterfly Yellow Blotch and three plants of Delta Yellow Blotch were sampled from each pack to record plant quality (shoot fresh weight and plant height). There was no significant effect of the long-day or night-break lighting treatments on fresh weight (*P*>0.05). As with flowering time, the main differences were due to sowing date (batch) and cultivar (*P*<0.001). Delta had more bulk when compared with Butterfly and the early sowing dates tended to be lighter as they flowered shortly after transplanting (Figure 9).

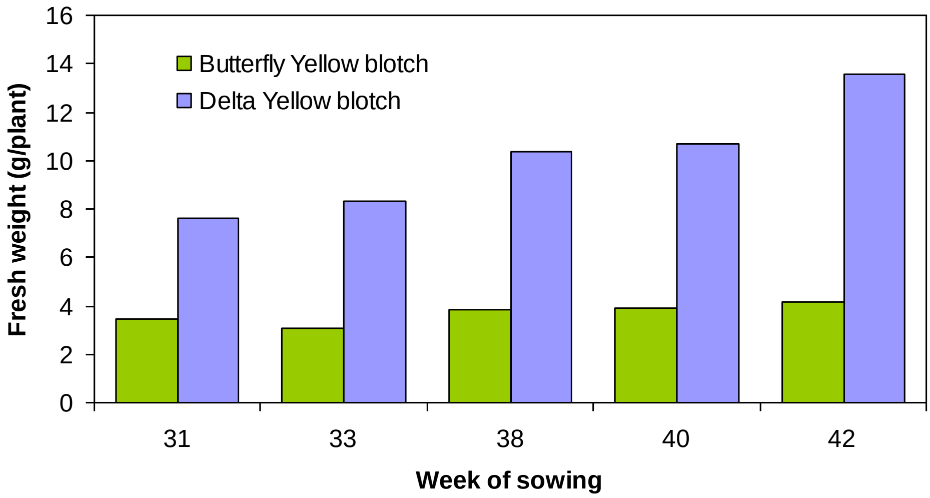


Figure 9. *The effect of sowing date (batch) and cultivar on the fresh weight of plants sampled when packs were marketable. The data are averaged across all of the daylength treatments (SED = 0.757; 82 d.f.).*

Plant height was also affected (*P*<0.001) by sowing date (Figure 10). While there was no significant difference (*P*>0.05) in the height of these cultivars grown on under different fixed daylengths (experiment 1), the plants grown on the floor with night-break lighting after potting up into packs were significantly taller (*P*<0.01); they were around 0.4cm taller than those grown under a natural daylength.

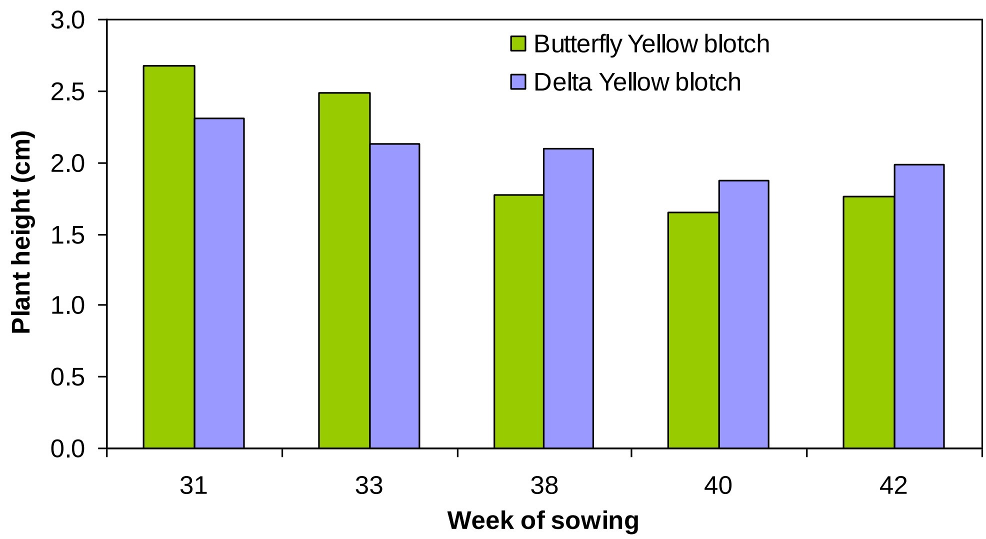


Figure 10. *The effect of sowing date (batch) and cultivar on plant height when packs were marketable. The data are averaged across all of the daylength treatments (SED = 0.1723; 82 d.f.).*

Flower numbers

Having reached the marketable stage packs were left for a further two weeks and the number of open flowers per pack were recorded to indicate whether the treatments affected flower numbers. Again there were significant effects (*P*<0.001) of both sowing date, and cultivar (Figure 11).

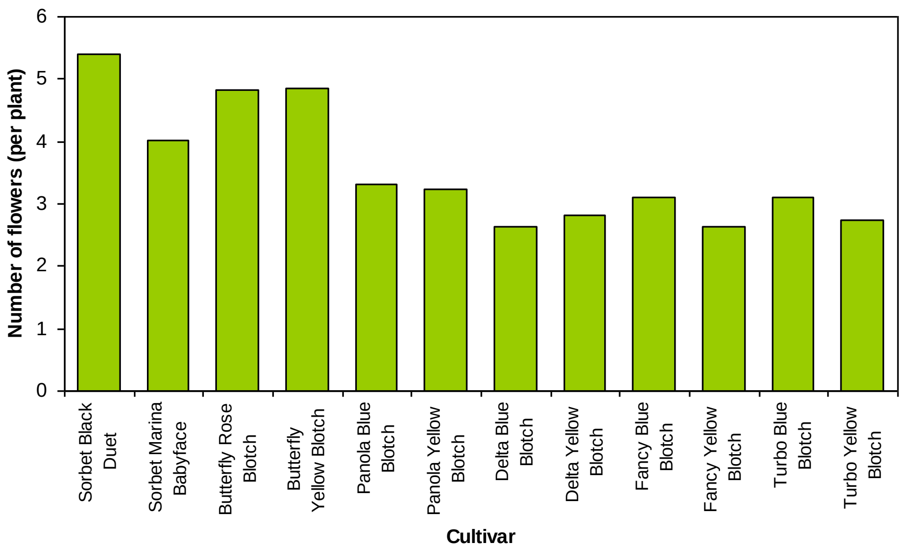


Figure 11. *The effect of cultivar on the average number of flowers (open and dead) per plant two weeks after packs were marketable. The data are averaged across all of the batches and treatments (SED = 0.1908; 661 d.f.).*

The fixed daylength treatments (expt. 1) did not have a significant effect on the number of open flowers. However, as with flowering time, there was a small but significant effect (*P*<0.01) of the night-break lighting treatment after potting up into packs. Night-break lighting increased the average flower number (open and dead flowers) two weeks after marketing from 3.4 to 3.7 per plant (Figure 12).

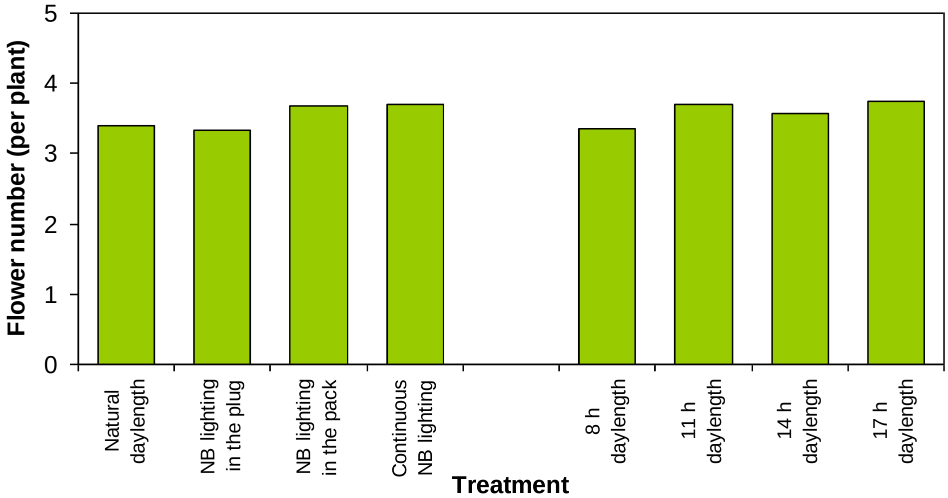


Figure 12. *The effect of daylength treatment on the average number of flowers (open and dead) per plant two weeks after packs were marketable. The data are averaged across all of the batches (SED for comparison of NB lighting treatments (expt. 2) = 0.1513; 190 d.f., SED for comparison of fixed photoperiods (expt. 1) = 0.1745; 293 d.f.).*

Discussion

The work conducted as part of year 1 showed that violas from the Sorbet and Butterfly series showed little or no response to day-extension or night-break lighting, despite the fact that winter flowering pansies have been shown to be quantitative long day plants (Hughes and Cockshull 1966; Adams *et al.,* 1997; Runkle and Heins, 2003). This may have been due to the fact that these viola cultivars are day-neutral or because the plugs were raised commercially and initiated before the treatments were applied to packs. Therefore, the current work included a range of pansy cultivars and daylength treatments were applied to both plugs and packs.

The current trial showed no significant effect of day-extension lighting, and only a very small effect of night-break lighting. Plants were lit throughout production and so the unexpected results in year 2 are clearly not due to the treatments being applied too late in production. This is backed up by the fact that the effect of night-break lighting in experiment 2, although small, appeared to be greatest in packs. Therefore, the results would tend to suggest that the modern cultivars examined are practically insensitive to daylength. However, there is another possible explanation; the lack of response to lighting could have been due to light quality.

Fluorescent lamps were chosen for the lighting treatments to minimise the stretching that often occurs with tungsten lamps. The fluorescent lamps proved suitable in this regard, in that the effects on plant height were minimal. However, the light quality from these lamps may have been inappropriate to stimulate a long-day response. Great care is needed when switching from tungsten to fluorescent lamps for night-break lighting. A 15W compact fluorescent lamp sold as having an equivalent output to a 60W tungsten bulb will not be comparable for horticultural purposes as the manufacturers do their conversion in lux, which is related to what the human eye perceives, rather than PAR (photosynthetically active radiation; 400 – 700 nm). The general rule of thumb for short-day species is that, providing that the PAR output is comparable, the lamps should be suitable for night-break lighting. These results question whether that assumption is correct. Indeed other trials such as the perennials work at STC (PC 246) have shown no response to night-break lighting with fluorescent lamps for species known to be long-day plants. Furthermore, recent work on antirrhinum at Warwick HRI has shown that 7$\mu mol/m^2/s^{-1}$ of fluorescent lighting (three times the irradiance that would normally be used with tungsten bulbs) was insufficient to fully promote a long-day response when given as an 8 hour day extension. Given the increasing popularity of compact fluorescent lamps and the pressure to switch to these to save energy, it is important that further work is done to investigate their suitability for day-extension and night-break lighting particularly for long-day species.

References

Adams SR, Pearson S, Hadley P. 1996. Modelling growth and development of pansy cv. Universal Violet in response to photo-thermal environment: Application for decision support and scheduling. *Acta Horticulturae* 417: 23-32.

Adams SR, Pearson S, Hadley P. 1997. The effects of temperature, photoperiod and light integral on the time to flowering of pansy cv. Universal Violet (*Viola x wittrockiana* Gams.). *Annals of Botany* 80: 107-112.

Hughes AP, Cockshull KE. 1966. Effects of night-break lighting on bedding plants. *Experimental Agriculture* 16: 44-52.

Runkle ES, Heins RD. 2003. Photocontrol of flowering and extension growth in the long-day plant pansy. *Journal of the American Society of Horticultural Science* 128: 479-485.

Appendix 1 – Experimental plan:

Compartment layout: