Project title:	The Bedding and Pot Plant Centre – new product opportunities for bedding and pot plant growers
Project number:	PO 019
Project leader:	Dr Jill England, ADAS Boxworth
Report:	Annual report, March 2016
Key staff:	Dr Jill England (ADAS), Horticulture Consultant Chloe Whiteside (ADAS), Horticulture Consultant David Talbot (ADAS), Horticulture Consultant
Location of project:	Baginton Nurseries, Coventry, Warwickshire
Industry Representative:	Caroline Shove, Bryants Nurseries Ltd, Water Lane, Bovingdon, Hemel Hempstead, Hertfordshire, HP3 0NA
Date project commenced:	July 2014
Date project completed (or expected completion date):	March 2017

DISCLAIMER

[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

AUTHENTICATION

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

Dr Jill England

Horticulture Consultant

ADAS

Signature .... Date ....

Chloe Whiteside

Horticulture Consultant

ADAS

Signature .... Date ....

David Talbot

Horticulture Consultant

ADAS

Signature .... Date ....

Report authorised by:

Dr Barry Mulholland

Head of Horticulture

ADAS

Signature .... Date ....

CONTENTS

GROWER SUMMARY

Headline

- Seed-raised varieties of *Begonia boliviensis* and *Calibrachoa* perform well relative to vegetative varieties.
- FlowersOnTime predicted time to flower within ± 7 days tolerance levels for some species (*Salvia splendens* Vista and French marigold Durango), but not all that were tested under UK conditions.
- Spectral filters were demonstrated to be useful aids to achieve plant growth control (Lumisol and Luminance) and crop scheduling (SunSmart Blue), although the effects are species dependent.

Background

Objective 1: Seed vs cutting varieties of Begonia boliviensis and Calibrachoa

Recent breeding programs have produced new seed grown varieties of *Begonia boliviensis* and *Calibrachoa* that provide growers with the opportunity to take advantage of potentially less expensive plant material. As consistent plant quality is an industry requirement, and seed produced varieties are potentially more variable than vegetative varieties, a comparison of seed vs vegetative production in terms of inputs, quality and costs was carried out.

Objective 2: Temperature effect on days to flowering

With energy costs constantly increasing, growers are having to produce high quality products with lower inputs whilst maintaining production schedules. Researchers in the USA, the Floriculture Research Alliance, have developed an Excel spreadsheet based decision making tool (FlowersOnTime), to help growers explore the influence of average daily temperature on flowering time for their crops. The guide is based on data collected for over 60 crops, and uses the grower's standard crop production time and temperature to predict the effect of changing air temperature on time to flowering, assuming that all other conditions (e.g. photoperiod and daily light integral) remain unchanged. The model created has tolerance levels of ± 7 days, depending on location due to variation in factors such as light level. It was considered that this tool may be useful to growers during cool seasons to predict flowering, so that growers could achieve marketing with minimum additional heat input. This would be of most benefit to those growers with a specific marketing date as opposed to providing plants ready for marketing throughout the season. An alternative may be to use the tool to calculate transplant dates, for example if growing at a set temperature suitable for the crop, or if growing early season plants over a longer period when space is not at a premium.

Objective 3: Demonstration of spectral filters (film)

Growers are keen to reduce their reliance on chemical inputs through adoption of cultural and non-chemical means, and this can include the use of spectral filters (films). A range of spectral filters (films) is available to growers, capable of manipulating the light spectra afforded to the crop beneath, influencing plant growth and quality, and incidence of some pests and diseases. Diffusing filters can influence plant quality through deeper penetration of light into the crop. SunSmart Blue is promoted as reducing plant height and is used by growers to hold plants back until marketing. Demonstration of the potential benefits and drawbacks of the various spectral filters on the market will help to inform grower decision making.

Summary

Objective 1: Seed vs cutting varieties of Begonia boliviensis and Calibrachoa

Work was carried out between March and June 2015. Plugs of seed (s) and vegetatively (v) propagated varieties of *Begonia boliviensis*: Bossa Nova (s), La Paz (s), Santa Cruz Sunset (s) and Million Kisses Armour (v) and *Calibrachoa*: Kabloom (s), Crave (s), Aloha Kona (v), Cabaret (v) and Callie (v) sourced from a range of breeders / suppliers were transplanted into both pots (10.5 cm and 9 cm respectively) and 6-packs in weeks 11 and 13, using a peat (60%) / woodfibre (40%) growing medium. Three weeks post-transplant (week 14 and week 16), a sub-sample of three healthy plants representative of each variety was transplanted into 30 cm rattan baskets and grown on under glass before being moved outdoors in week 21; plants were treated with common crop protection strategies.

***Begonia boliviensis*.** All *Begonia* varieties produced good quality plants from both transplant weeks, with the exception of *B*. Santa Cruz Sunset, which was slower to establish than the other varieties, and more fragile with some breakages occurring during transplanting. The *B.* Santa Cruz Sunset also flowered unevenly, with week 11 transplants coming into flower later than the week 13 transplants. For all varieties the quality score was greater for those transplanted in both week 13 than week 11 (**Figure 1**) when assessed two and three weeks after transplant (WAT). For *B*. Bossa Nova and *B*. Million Kisses Amour, the high quality scores were maintained through to the final assessment, 9 and 7 WAT (for week 11 and 13 transplants respectively)

B. Million Kisses Amour, the sole vegetative *Begonia* included in this trial, achieved high quality scores and was favoured by growers. However, there were also promising seed-

raised varieties. *B.* Bossa Nova in particular scored well for quality – particularly for the later transplant date, and there was also less difference in plant height across the two transplant dates, suggesting it may be less responsive to variation in the environment than other varieties.

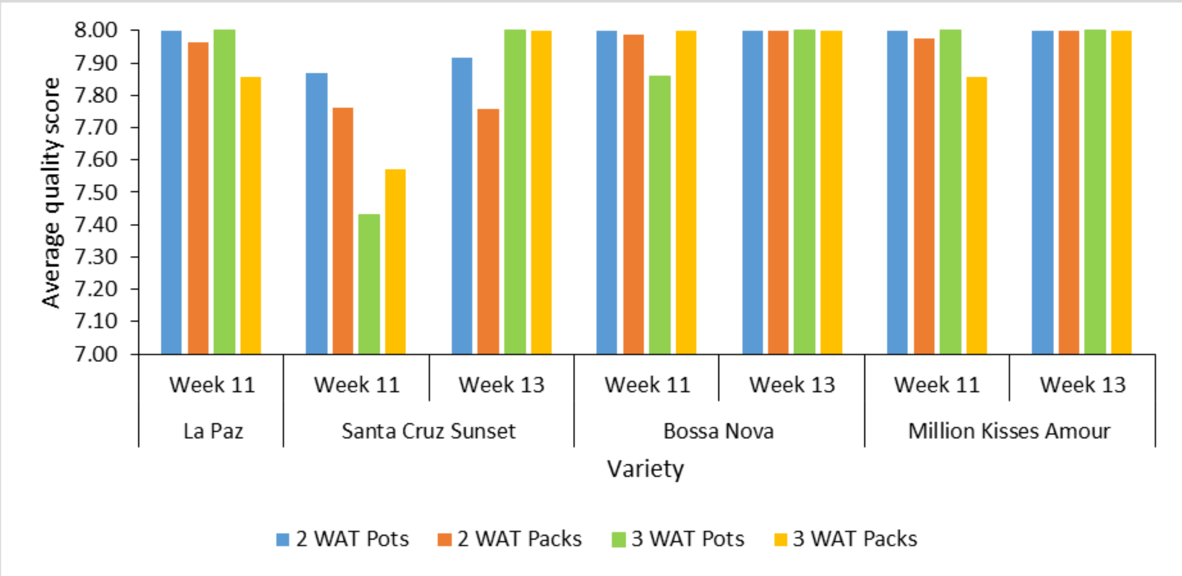


Figure 1. *Begonia boliviensis* average quality scores assessed 2 WAT (26 March and 2 April respectively) and 3 WAT (9 April and 16 April respectively) Scoring: 1 = poor, 9 = exceptional. Scoring based on number of flowers, flower colour, foliage colour, plant habit and consistency.

Calibrachoa. Quality scores for the *Calibrachoa* were more varied than for the *Begonia.* However, *C.* Kabloom, *C.* Cabaret and *C.* Callie all scored well for quality when assessed two and three WAT (**Figure 2**). *C.* Aloha Kona and *C.* Cabaret generally achieved good scores, including the highest grower scores for week 11 and 13 transplants respectively. *C*. Kabloom (seed-raised) scored consistently well for quality, showed less variation in height (2 and 3 WAT), and was scored favourably by growers.

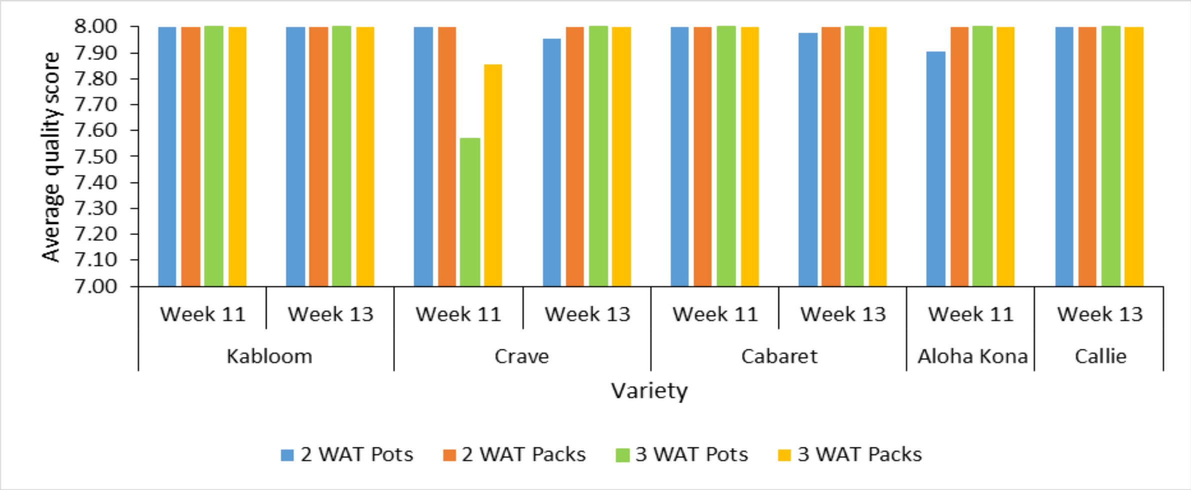


Figure 2. *Calibrachoa* average quality scores assessed 2 WAT (26 March and 2 April respectively) and 3 WAT (9 April and 16 April respectively) Scoring: 1 = poor, 9 = exceptional. Scoring based on number of flowers, flower colour, foliage colour, plant habit and consistency.

For this trial, it was necessary to provide the same inputs, for example water volume, to all varieties to allow for comparisons, and this is likely to have affected quality in some varieties that may favour a different regime. Whilst the *C.* Kabloom and *C.* Aloha Kona produced in this trial were compact and well branched, other varieties (e.g. *C*. Crave or *C*. Callie) may require more pinching, particularly if the production time is protracted through transplanting into larger containers or hanging baskets. Growers will need to select varieties and fine tune inputs to suit their own site and production regime. This trial suggests that the new seed-raised varieties of both *Begonia boliviensis* and *Calibrachoa* should compete well against vegetative varieties.

Table 1. Seed vs cutting varieties of *Begonia boliviensis* and *Calibrachoa* production cost comparison. *Exclusive of royalties. †Inclusive of delivery costs. S = seed; v = vegetative.

Variety	Tray size	Cost (p/plug)*	Royalty (p/plug)	Total (p/plug)
Begonia Bossa Nova (s)	84	36.50	0	36.50
Begonia Santa Cruz Sunset (s)	84	53.95†	0	53.95†
Begonia La Paz (s)	180	36.00	0	36.00
Begonia Million Kisses Amour (v)	66	52.11†	6.2	58.31†
Calibrachoa Kabloom (s)	84	32.13†	0	32.13†
Calibrachoa Crave (s)	84	32.13†	0	32.13†
Calibrachoa Cabaret (v)	84	32.13†	4.1	36.23†
Calibrachoa Aloha Kona (v)	128	20.50	4.1	24.60
Calibrachoa Callie (v)	128	30.00	3.7	33.70

Costs

An assessment of inputs identified that in this trial, for both the *Begonia* and *Calibrachoa* there was no difference between varieties; for example fungicides and growth regulators were applied to all varieties of *Calibrachoa* and similarly, fungicides were applied to all varieties of *Begonia* (**Table 1**). Costs were also influenced by the variety, tray / plug size, and delivery costs. Some suppliers included the delivery cost in the price per plug and were unable to provide price net of delivery. Royalties are not payable on seed-raised varieties which suggests that overall they ought to be cheaper than vegetative varieties. Whilst this was borne out for the *Calibrachoa*, it was less clear for the *Begonia* as the plug price was inclusive of delivery. Smaller plugs (more plugs per tray) were less costly but the plants achieved a similar plant size as those from larger plugs within the timeframe of this trial, although they may have taken longer to achieve pot cover. The plants for this trial were produced from plugs, but production may prove more profitable through on-site propagation from seed (or cuttings), subject to the availability of appropriate expertise and facilities (e.g. early season heat).

Objective 2: Temperature effect on days to flowering

Work was carried out between March and May 2015. Plugs of five plant species (*Dianthus* Festival mixed, *Petunia* Frenzy Select mixed, *Verbena* Quartz XP mixed, French marigold Durango red and *Salvia Splendens* Vista mixed) were transplanted as plugs into black 6-packs. They were grown on under glass, in three different temperatures; 16°C (T1), 18°C (T2) and 19°C (T3).

For most of the species, there was a notable difference in flowering time between the three treatment areas (**Table 2**), particularly with *Petunia* where plants grown at 19°C came into flowering 15 days earlier than those grown at 16°C. This was also the case for *Salvia*, with plants growing at both 18°C and 19°C coming into flower earlier than those grown at 16°C. For *Dianthus,* there was no difference in flowering time between 18°C and 19°C, and for French marigold, plants grown at both 16°C and 18°C came into flower at the same time. For the *Verbena*, there was no difference in flowering time between any of the treatments. For all species tested, flower number increased with temperature under these conditions.

Achieved production time of French marigold and *Salvia splendens*, was predicted within the tolerance level of $\pm$7 days of the FlowersOnTime tool (**Table 2** and **Figure 3**), even though the temperatures used for this trial were at the top end of the range used to construct the model.

Table 2. Number of days from transplant to first flower. Values in brackets are number of days to first flower predicted by the FlowersOnTime tool. *This temperature was outside the range of the FlowersOnTime tool.

Variety	T1: 16°C	T2: 18°C	T3: 19°C*
Dianthus ‘Festival’	40 (26)	32 (23)	32 (n/a)
French marigold	25 (26)	25 (23)	19 (n/a)
Petunia ‘Frenzy’	40 (24)	32 (20)	25 (n/a)
Salvia splendens ‘Vista’	40 (31)	25 (25)	25 (n/a)
Verbena ‘Quartz XP’	40 (26)	40 (23)	40 (n/a)

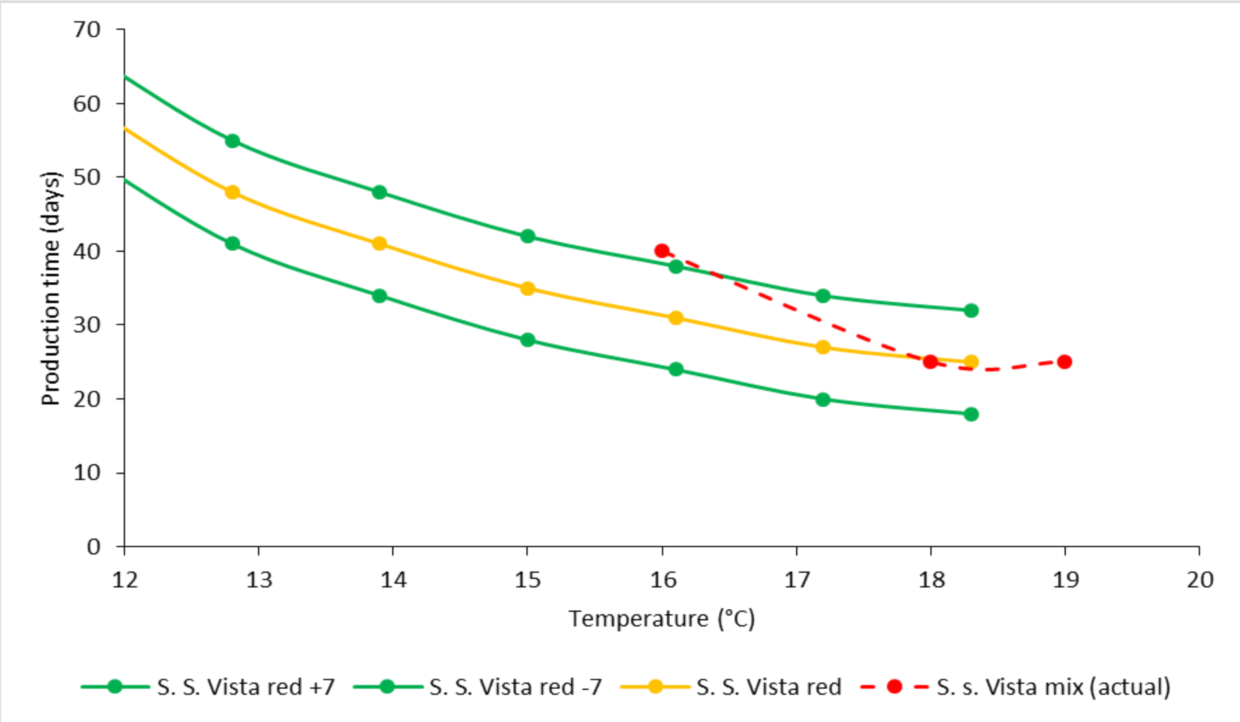


Figure 3. FlowersOnTime prediction vs actual flowering time – *Salvia splendens* Vista mix

Objective 3: Demonstration of spectral filters (film)

Four separate polytunnels with SunSmart Blue (new and old to test potential degradation), Lumisol and Luminance coverings, with a glasshouse ‘control’ were assessed between April and June 2015. 10 plant species (*Ageratum* ‘Champion Blue’, *Lobelia* ‘Regatta’ mix, *Antirrhinum* ‘Liberty’ mix, *Pansy* ‘Matrix’ spring select mix, *Dianthus* ‘Festival’ mix, *Petunia* ‘Frenzy’ mix, French marigold ‘Durango’ mix, *Salvia* ‘Vista’ red, Geranium ‘Horizon’ mix and *Viola* ‘Sorbet XP’ spring select mix) potted into 6-packs (black plastic) using a peat (60%) / woodfibre (40%) growing medi were grown under the different tunnels to demonstrate impact on production.

Of the light diffusing spectral filters (Lumisol and Luminance), Luminance generally produced more compact plants than those produced under glass, although with some variation between species. Plant quality was also generally commercially acceptable; diffused light affects plant quality by providing a more even temperature at plant level, reducing the potential for 'hot spots' of light on foliage, and the scattered light reaches deeper into the crop reducing shading of lower leaves. The light spectrum under the two plastics was similar in the longer wavelengths e.g. far red. Luminance transmitted more light than lumisol in the red and green (3%), blue (4%) and UVA (9%) regions of the spectrum.

SunSmart Blue can delay flowering and hold plants back, however in this trial the Lumisol treatment limited growth more successfully. There were slight differences in the light spectra and light transmission afforded by the two SunSmart Blue tunnels due to slight sun damage to the older tunnel cover. However, these plastics transmitted apporoximately 40% of available PAR light, with proportionally greater transmission in blue (~65%) than green (51%), red (21%) or UVA (21%) region of the spectrum. Within this trial, generally, flowering was delayed, plant quality was higher and growth greater under the new SunSmart Blue tunnel, suggesting that growers will need to monitor the effects of these tunnel covers over time and replace them should any deterioration affect plant quality or scheduling. However, as there was no replication of structures, the statistical significance of these results cannot be established. It is clear from these results that different plant species respond differently to the changes to the environment afforded by the spectral filters and growers need to be aware of these effects when planning their use within a production programme.

Financial Benefits

- For the *Begonia boliviensis* and *Calibrachoa* the cost benefits were influenced by variety, tray / plug size and delivery costs. Seed-raised varieties did not incur royalties, (3.7 – 6.2p/plug). Smaller plugs (more plugs per tray) were less costly but the plants achieved a similar plant size as those from larger plugs within the timeframe of this trial. Further financial benefits may be gained through on-site production from seed or cuttings.
- Confident prediction of days to flower under the variable conditions UK growers experience would help to reduce waste and contain costs by applying the minimum amount of heat necessary to meet target marketing dates. For the French marigold, the number of days to flowering was increased by 15 days when the temperature was reduced by 2˚C (from 18˚C to 16˚C). Using a published scenario (Adams et al. 2009), a reduction of 1˚C (from 14˚C to 13˚C) provided a 13% reduction in energy use (42 kWh/m2/annum in the model used) in a low-input ornamental crop (vent 16˚C, no humidity control, no minimum pipe temperature and no thermal screen). At an average 10p/kWh

(www.businesselectricityprices.org.uk), this equates to 420p/m2/annum, and a 1.15p/m2/day saving in energy cost and can be considered against an estimated crop value of £29.6/m2 (double 6-packs, 0.082/m2) to the grower. These estimates would vary depending on the nursery infrastructure, energy costs, and heating system used. Consideration would also need to be given to the potential increase in crop protection costs at lower temperatures.

- Spectral filters can help to reduce inputs e.g. plant growth regulators, and reduce waste by holding plants back to meet marketing schedules. As an example, the value associated with a standard single span polytunnel (4 m x 20 m) of mixed bedding in standard double 6-packs (dimensions 0.082 m2) that would otherwise be wasted is estimated at £2,341, assuming all plants are marketed. The cost to cover the polytunnel with SunSmart Blue film (£0.88 /m2) is estimated at £209, excluding labour and fittings. Although plant growth regulators were not used in this trial, the cost of a single application of Bonzi (as paclobutrazol, 1.25 ml/L) to hold the plants back for dispatch would be £1.90 + VAT (20 ml Bonzi) plus the cost of the labour and equipment to apply it. This would need to be applied to each crop the tunnel is used for, while the tunnel cover is marketed with a life expectancy of 7-8 years.

Action Points

- Seed raised *Begonia boliviensis* and *Calibrachoa* compete well with vegetative varieties, and growers should consider trialling plants on their own sites to further investigate the the best varieties to grow for quality and economics.
- Spectral filters (films) demonstrated features beneficial to growers:
    - SunSmart Blue can be used to hold batches of plants back to meet specific marketing dates. This appears to be achieved through the cooler environment and lower light transmission.
    - Light diffusing films, e.g. Luminance produce good quality, compact plants, provide a more even temperature at plant level and a cooler working environment.
    - As there variation in plant response to the various products available, close monitoring will determine the most appropriate varieties for each situation.

SCIENCE SECTION

Introduction

The total value of the UK commercial horticulture sector in 2011 has been estimated at £2,714 million, of which protected non-edibles accounted for in the region of 12%, equating to £326 million. The index of producer prices shows that, on average, ornamentals are 68% more expensive than in 2005, however, input prices have also risen significantly during the same period, particularly for fertilisers and soil improvers, heating fuel and plant production products (up 121%, 102%, and 6% respectively) (Crane *et al*., 2013), demonstrating the importance of minimising inputs. Glasshouse production output for the pot and pack bedding sector peaks with spring and summer bedding, and dips over the autumn/winter period, when growers seek new market opportunities to maximise production during the quieter autumn and winter season.

Key to increasing production and profitability are: 1) to extend the season with new crops or varieties, producing niche crops for specific markets, value added products (e.g. hanging baskets and planted arrangements in pots) and taking advantage of the new, innovative and exciting breeding lines that become available to provide consumers with increased choice, 2) utilising breeding techniques to solve production (e.g. pest and disease) issues and 3) reduce inputs (e.g. pesticide, plant growth regulator, fertiliser, water and energy use).

The Bedding and Pot Plant Centre (BPPC), located at Baginton Nurseries, near Coventry, has been established to address the needs of the industry through undertaking a programme of work over two years to trial and demonstrate new product opportunities, demonstrations and practical solutions to problems encountered on nurseries. Knowledge transfer events including trial open days and study tours are also included in the programme.

The work programme is guided by a grower-led Management Group that includes grower members of the BPOA Technical Committee along with a representative from the host nursery. The agreed work programme for the first year of the Bedding and Pot Plant Centre covered the following themes:

1. New plant variety introduction (Calibrachoa and Begonia boliviensis)

Breeders, seed houses and plant producers continually develop new breeding lines from which growers select those with visual appeal for consumers, precocious flowering lines and attractive colour ranges. Of key interest to growers are genetics that impart resistance to pests and diseases, but also compact plants that require no or minimal application of plant growth regulators, all of which enable premium quality plants to be produced with minimum input (pesticides, energy etc.), or that may be scheduled to meet a different or extended marketing window.

Recent breeding programs have produced new seed grown varieties of *Calibrachoa* and *Begonia boliviensis* that provide growers with the opportunity to take advantage of potentially less costly plant material. As consistent plant quality is an industry requirement, and seed produced varieties are potentially more variable than vegetative varieties, a comparison of seed vs vegetative production in terms of inputs, quality and costs was required.

2. Temperature effect on days to flowering

The spiralling cost of energy has increased the imperative to produce good quality products with lower inputs whilst maintaining production schedules. Whilst some varieties may be suitable for production under cooler regimes, the trade-off is often reduced plant size and quality that may need to be compensated for with longer production times. Lower temperature and consequent higher humidity increase disease pressure that may also result in higher crop protection inputs. Plants have a species dependent optimum temperature for plant quality, which is generally lower than the optimum for flowering. For example, for *Petunia* ‘Purple Wave’, each temperature decrease of 1ºC will delay flowering by approximately three days, whilst for *Viola* the same temperature reduction will delay flowering by one to two days, depending on the cultivar. Conversely, research has shown that reducing temperatures can promote flowering in some species, with increased flower size, number of flowers and branching (Brough, 2003, Warner *et al.,* 2002, Pearson *et al.,* 1995).

In the UK, data produced by growing a range of bedding plant species under different combinations of temperature, photoperiod and light integral were used to develop models and construct a tool (currently unavailable) to enable growers to determine optimal growing conditions and the most economic regime for the crops tested (Pearson *et al.,* 1993; Pearson, 1996; and Pearson, 1997). In the USA, the Floriculture Research Alliance has developed an Excel spreadsheet based decision making tool, FlowersOnTime, (FlowersOnTime: http://www.floriculturealliance.org/research_outputs.asp?id=17&cid=2&type), free to download from the internet to help growers explore the influence of average daily temperature on flowering time (Fisher *et al.,* 2011). The guide is based on data collected for in excess of 60 crops, and uses the grower’s standard crop production time and temperature within their model to predict the effect of changing air temperature on time to flowering (**Figure 4**). The developers explain that the tool is based on research with limited cultivars and experimental conditions, where scientists grew plants under a range of temperatures and recorded flowering time. Researchers fitted predictive curves to the data (degree day or thermal time models) to produce a model that works on the premise that (a) there is a "base temperature" below which plants do not develop towards flowering, (b) crop time decreases as the temperature increases above the base temperature, and (c) with some crops there can be an "optimum temperature" above which crop time is no shorter (or can actually be longer) as temperature increases. The developers state that production times may vary by ± 7 days depending on location due to variation in factors such as light level. This could be a useful tool for UK growers to use as a guide and could help them to predict the effect of growing plants under cooler conditions. The model was tested under UK growing conditions by comparison of predicted and actual flowering times for five ornamental species at three temperatures.

Species/Cultivar:		Salvia splendens: Vista Red
Standard crop time (days):		25
Standard production temperature (°C):		15
Temperature units (C or F):		c
Base Temperature (°C):		7
Optimum Temperature (°C):		N/A
Expected production times		
°F	°C	Days
53	11.7	43
55	12.8	35
57	13.9	29
59	15.0	25
61	16.1	22
63	17.2	20
65	18.3	18

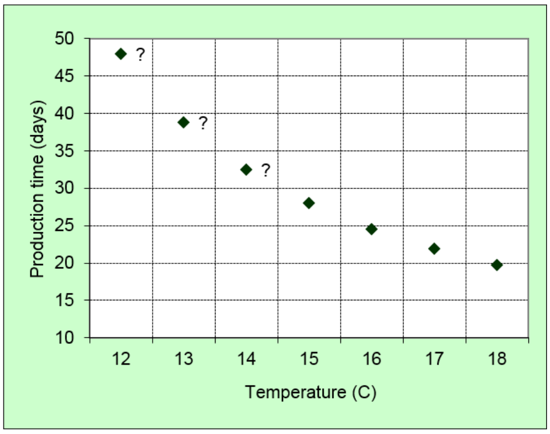


Figure 4. Example of the FlowersOnTime tool: Production times for *Salvia splendens* Vista Red

3. Industry use of spectral filters (films)

Growers are keen to reduce their reliance on chemical inputs through adoption of cultural and non-chemical means, and this can include the use of spectral filters (films) to control growth and aid scheduling. A range of spectral filters (films) is available to growers, capable of manipulating the light spectra afforded to the crop beneath influencing plant growth and quality, and incidence of some pests and diseases. Plant architecture, for example, is directly regulated by light through the ratio of red:far-red light and the proportion of blue light; the red:far-red light ratio which inhibits stem elongation and promotes lateral branching in many bedding plant subjects. Previous work using spectral filters indicated that both Solatrol and UV-T (UV transparent) filters can successfully control growth in bedding plants, although not all plant species are responsive (Pearson, 2000 and Huey, 2006). Light diffusing filters can influence plant quality through deeper penetration into the crop and reducing ‘hot spots’ at plant level. SunSmart Blue is promoted as reducing plant height and is used by growers to hold plants back until marketing. The back catalogue of research and knowledge has not been widely adopted by the Industry to date, but demonstration of the potential benefits and drawbacks would help to inform grower decision making.

Project objectives (Year 1)

Objective 1. To investigate the scheduling, performance and cost implications of seed vs vegetative varieties of *Calibrachoa* and *Begonia boliviensis.*

Objective 2. To investigate the potential use of the FlowersOnTime tool to guide/inform decision making on temperature manipulation to achieve target marketing dates under UK conditions.

Objective 3. To demonstrate the use of spectral filters (films) on nurseries

Materials and methods

Objective 1: Seed vs cutting varieties of Begonia boliviensis and Calibrachoa

The trial was carried out between March and June 2015. Plugs of nine varieties of *Begonia boliviensis* and *Calibrachoa* (**Table 3**), were sourced from a range of breeders and transplanted into both pots (10.5 cm and 9 cm respectively) and 6-packs in weeks 11 and 13 using a peat (60%) / woodfibre (40%) growing medium. Plants were grown on benches under glass with overhead irrigation and fed with Universol Soft 113R liquid feed at 1% at every irrigation from four weeks after transplant (WAT). Plants were monitored for pests and diseases and fungicide and insecticide treatments applied as necessary. Pots and packs were laid out in a randomised block design (seven replications), with each plot comprised of two 6-packs and 12 pots (total 24 plants). Three weeks post-transplant (week 14 and week 16) a sub-sample of three healthy plants with good root structure, representative of each variety was transplanted into 30 cm rattan baskets; three plants per basket, three replicate baskets per variety, for both pots and packs and for each transplant date (total of 12 baskets per variety). Hanging baskets were randomised and suspended from glasshouse stanchions. The baskets of plants were grown on under glass with an equal volume of irrigation provided to each variety via drip irrigation until they were moved outdoors in week 21.

C. Crave (S), *C.* Kabloom (S) and *C.* Cabaret (V) were pinched by the propagator; *C.* Callie (V) and *C.* Aloha Kona (V) were neither pinched by the propagator nor during the trial. The *Begonia* were not pinched. One application of the plant growth regulator B-Nine SG, (daminozide, 1 g/L water) was made to the *Calibrachoa*. Two applications of Amistar (azoxystrobin, 1 ml/L water) were applied to both the *Begonia* and *Calibrachoa*.

Table 3. *Begonia boliviensis* and *Calibrachoa* varieties used in the seed vs cutting trial (2015). *week 11 only. **week 13 only.

Species	Variety	Seed / vegetative	Breeder	Supplier
Begonia boliviensis	Bossa Nova	Seed	FloraNova	Pentland Plants
	La Paz*	Seed	Volmary	Delamore Young Plants
	Million Kisses Amour	Vegetative	Fred Yates	Ball Colegrave
	Santa Cruz Sunset	Seed	Benary	Ball Colegrave
Calibrachoa	Aloha Kona*	Vegetative	Dummen Orange	Roundstone Nurseries
	Cabaret	Vegetative	Ball FloraPlant	Ball Colegrave
	Callie**	Vegetative	Syngenta	Syngenta
	Crave	Seed	PanAmerican	Ball Colegrave
	Kabloom	Seed	PanAmerican	Ball Colegrave

Assessments:

Inspections and assessments are summarised in **Table 4** and below:

- Plant quality was assessed on a scale of 1-9 (1 = poor quality; 7 = commercially acceptable; 9 = high quality), taking into account the number of flowers per basket, flower colour, foliage colour, plant habit and consistency between baskets.
- Root development was assessed for healthy, well developed roots.
- Plant height was measured between the compost surface and the top of the plant (3 plants/tray).
- Photographs were taken throughout the trial.
- Temperature and humidity were recorded throughout the trial using TinyTag data loggers (30 min intervals).

Table 4. Summary of trial inspections and assessments (2015)

Date	Week No.	Trial stage (WAT)*	Assessment
13 March	11	Pre-transplant into pots & packs (batch 1)	Plant quality, root quality (5 plants/tray), plant height (3 plants/tray)
26 March	13	Pre-transplant into pots &packs (batch 2)	Plant quality, root quality (5 plants/tray), plant height (3 plants/tray)
26 March	13	2 WAT (batch 1)	Plant quality, plant height
2 April	14	3 WAT (batch 1)	Plant quality, plant height
9 April	15	2 WAT (batch 2)	Plant quality, plant height
16 April	16	3 WAT (batch 2)	Plant quality, plant height
7 May	19	8 WAT (batches 1 and 2, in baskets)	Inspection
13 May	20	7 & 9 WAT (batches 1 and 2, in baskets)	Grower assessment. Plant quality
13 May	20	7 & 9 WAT (batches 1 and 2, in baskets)	ADAS assessment. Plant quality

*WAT = weeks after transplant into pots and packs

Objective 2: Temperature effect on days to flowering

The trial looking at temperature effect on the number of days to flowering was carried out between March and May 2015. Five plant species (**Table 5**) were transplanted into 6-packs (black plastic) using a peat (60%) / woodfibre (40%) growing medium, and grown on in three different areas of the same glasshouse, providing three temperature zones. Each area was known to have a different temperature, with the mean daily temperatures for each area recorded as 16°C (T1), 18°C (T2) and 19°C (T3). The three treatment areas were located either on the mypex covered floor (T1 and T2), or a bench (T3). Within each treatment area, packs were arranged in a randomised block design (four replications), with each plot comprised of four 6-packs (total 24 plants).

Plants were grown as a commercial crop, with overhead irrigation and fed with Universol Soft 113R liquid feed at 1% at every irrigation from four WAT. Plants were monitored for pests and diseases and fungicide and insecticide treatments applied as necessary.

Table 5. Plant varieties used in the temperature effect on days to flowering trial (2015).

Plant species	
Dianthus Festival mixed	*Salvia Splendens* Vista mixed
French marigold Durango red	*Verbena* Quartz XP mixed
Petunia Frenzy Select mixed	

Assessments

Inspections and assessments are summarised in **Table 6** and below:

- Plant quality was assessed on a scale of 1-9 (1 = poor quality; 7 = commercially acceptable; 9 = high quality), taking into account, foliage colour, general vigour, plant habit and consistency.
- Plant height was measured between the compost surface and the top of the plant (pre-transplant, 10 plants / tray; within treatments, all plants / plot).
- Root development was assessed for healthy, well developed roots (10 plants / plug tray).
- Date of first flower and number of flowers per plot.
- Photographs were taken throughout the trial.
- Temperature and humidity were recorded throughout the trial using TinyTag data loggers (30 min intervals).

Table 6. Trial inspections and assessments (2015)

Date	Week No.	Trial stage (WAT)*	Assessment
19 March	11	Pre-transplant	Plant quality, root quality, plant height
09 April	14	3 WAT	Plant quality, plant height, open flowers
16 April	15	4 WAT	Inspection
30 April	17	6 WAT	Open flowers, final assessment

*WAT = weeks after transplant

Objective 3: Demonstration of spectral filters (film)

The spectral filters trial was carried out between April and June 2015, utilising four separate polytunnels with SunSmart Blue (new and old), Lumisol and Luminance coverings, and a glasshouse (**Table 7**). 10 plant species (Table 8) were potted into 6-packs (black plastic) and each plot was replicated four times (48 plants per species per treatment). The potential degradation of film over time was investigated through use of a tunnel that had been covered with SunSmart Blue film in 2009, and a further tunnel that was recovered with new SunSmart Blue polythene in February 2015.

Table 7. Details of spectral filter treatments examined in 2015

Treatment	Effect on light	Expected effect on plants
Untreated glass	UVA / B (<400 nm) absorbed by glass.	Expect taller plants.
Luminance (tunnel)	Light diffusion, reduced infra-red transmission	Scatters light, enabling greater light penetration into crop. Fewer ‘hot spots’ at plant level. Improved plant quality.
Lumisol (tunnel)	Diffusion, UV transparent.	Greater light penetration into crop, reduced shading of lower leaves. Improved crop quality. Reduced stem elongation.
SunSmart Blue* (tunnels)	Light diffusion (30%), UV transparent.	Greater light penetration into crop, reduced shading of lower leaves. Improved crop quality.
	Blue (400- -500 nm) and green (500-600 nm) partially blocked.	100% blue light will cause plants to stretch, but a mixture of blue and red will result in more compact plants.
	Far red partially blocked.	More compact plants.
	Red/far red partially blocked.	Cooler environment.

*There were two SunSmart Blue tunnels, one covered in 2009 and the other in 2015.

Table 8. Plant varieties used in the spectral filters trial (films) (2015)

Plant species	
Ageratum ‘Champion Blue’	*Lobelia* ‘Regatta’ mix
Antirrhinum ‘Liberty’ mix	Pansy ‘Matrix’ spring select mix
Dianthus ‘Festival’ mix	*Petunia* ‘Frenzy’ mix
French marigold ‘Durango’ mix	*Salvia* ‘Vista’ red
Geranium ‘Horizon’ mix	*Viola* ‘Sorbet XP’ spring select mix

Plug plants were delivered to Baginton Nurseries and transplanted into 6-packs using a peat (60%) / woodfibre (40%) growing media. The Geranium were transplanted in week 14, and the remaining species in week 19. After transplanting, the plants were maintained under glass for two weeks to establish, and then transferred to the five treatment areas in week 21. Plants were grown as a commercial crop, with overhead irrigation and fed with Universol Soft 113R liquid feed at 1% at every irrigation from four WAT. Plants were monitored for pests and diseases and fungicide and insecticide treatments applied as necessary. However, no PGRs were applied to avoid confounding the effects of the treatments.

The plants were evaluated in a randomised block design within each treatment. It was not possible to replicate treatment areas, and the treatment structures used were diverse with regards to size, air volume etc., therefore statistical analysis of the results between treatments was not appropriate.

Assessments

Inspections and assessments are summarised in **Table 9** and below:

- Root development was assessed for healthy, well developed roots (5 plants/plug tray).
- Plant quality was assessed on a scale of 1-9 (1 = poor quality; 7 = commercially acceptable; 9 = high quality), taking into account, foliage colour, general vigour, plant habit and consistency.
- Plant height was measured between the compost surface and the top of the plant
    - Pre-transplant, 3 plants/tray
    - At transfer to treatments and four weeks after treatment, 5 plants/plot.
- Number of plants in flower per plot.
- Photographs were taken throughout the trial.
- Temperature and humidity were recorded throughout the trial using TinyTag data loggers (30 min intervals).
- Light spectra and transmission measurements were made on site on 22 June 15 (method detailed below).

Table 9. Summary of trial inspections and assessments (2015)

Date	Week No.	Trial stage (WAT*) / action	Assessment
02 April	14	Pre-transplant (Geraniums only)	Plant quality, root development (5 plants/tray), plant height (3 plants/tray)
07 May	19	Pre-transplant (Remaining varieties)	Plant quality, root development (5 plants/tray), plant height (3 plants/tray)
21 May	21	Transfer to treatments	Plant height (5 plants per plot), number of plants in flower
27 May	22	8 WAT (Geranium), 3 WAT (all other spp.)	Number of plants in flower
04 June	23	9 WAT (Geranium), 4 WAT (all other spp.)	Plant quality, plant height, number of plants in flower
11 June	24	10 WAT (Geranium), 5 WAT (all other spp.)	Number of plants in flower
18 June	25	11 WAT (Geranium), 6 WAT (all other spp.)	Plant quality, plant height, number of plants in flower
22 June	26	12 WAT (Geranium), 7 WAT (all other spp.)	Light transmission and spectra

*WAT = weeks after transplant

Light spectra and transmission measurements

Light measurements were taken by Dr Phillip Davis (STC), between 11am and 3pm on 22 June using a hand held portable Jaz spectroradiometer (Ocean optics). During the measurement period patchy cloud cover caused large variations in light intensity. To avoid noise in the data, measurements were only made when the sun was not obscured by clouds. Several measurements of direct sunlight outside were made before and after measurements were made within each of the trial areas to ensure changes in light intensity were accounted for in the measurements. Within each of the trial areas several measurements were made along the length of the polytunnels or bays of the glasshouse.

Measurements were performed in the five trial areas including four polytunnels and one glasshouse. Within the glasshouse, measurements were made when the screens were open and when the screens were closed.

The spectra presented are the mean of at least five measurements. Data were discarded if there was evidence of reduced light levels caused by cloud cover. Transmittance was determined as the mean spectrum within the trial area divided by the mean spectrum measured outside.

Results

Objective 1: Seed vs cutting varieties of Begonia boliviensis and Calibrachoa

Plants were monitored throughout the trial for pests and diseases. A preventative application of Amistar (azoxystrobin, 1 ml/L water) was applied to all varieties (*Begonia and Calibrachoa*), and a further application was made to all varieties as *Botrytis* developed in one *B.* 'Santa Cruz Sunset' plant that had sustained damage (**Table 10**).

Root development

The plugs generally had well developed healthy root systems that were even across the plug tray for both week 11 and week 13 transplant dates.

Plant quality

All plugs of both *Begonia boliviensis* and *Calibrachoa* were generally of high quality, with scores of 8.0 across all varieties in both transplant weeks, with the exception of *B*. Million Kisses Amour in week 13, which achieved an average score of 7.0 where plugs had failed or developed *Botrytis*.

Table 10. Seed vs cutting varieties of *Begonia boliviensis* and *Calibrachoa.* Detail of plant growth regulator and fungicide applications.

Variety	PGR (no. of applications)*	Fungicide (no. of applications)**
Begonia 'Bossa Nova'	0	2
Begonia 'La Paz'	0	2
Begonia 'Million Kisses Amour'	0	2
Begonia 'Santa Cruz Sunset'	0	2
Calibrachoa 'Aloha Kona'	1	2
Calibrachoa 'Cabaret'	1	2
Calibrachoa 'Callie'	1	2
Calibrachoa 'Crave'	1	2
Calibrachoa 'Kabloom'	1	2

*B-NINE SG (daminozide) **Amistar (azoxystrobin)

Begonia boliviensis

B. Million Kisses Amour (vegetative) scored consistently well for quality compared with other varieties, and achieved the highest quality scores across both transplant dates (**Figure 5** and **Table 11**). However, higher quality scores were sometimes achieved by those in pots than packs (2 and 3 WAT). Growers favoured those transplanted in week 11 in preference to week 13 transplants (from both pots and packs) when assessed 9 and 7 WAT (week 11 and 13 transplants respectively) on 13th May (refer to **Appendix 1** for grower comments and images).

B. Santa Cruz Sunset (seed) scored poorly compared with other varieties at all assessments across both transplant dates, from pots and packs. It was slower to establish and more fragile than other varieties so that some breakages occurred during transplant into baskets; the tissue wound became infected with *Botrytis*. This variety also flowered unevenly, with week 11 transplants coming into flower later than week 13 transplants. The quality score was affected by the more fragile nature of this variety and the effects of *Botrytis* when grown under the regime used for this trial.

Begonia Bossa Nova (seed) scored consistently well for quality both two and three WAT, however when assessed 9 and 7 WAT (week 11 and 13 transplants respectively) the growers scored this variety less favourably, particularly those potted in week 13, due to a degree of soft growth and stretch (**Figure 5, Table 11** and **Appendix 1**).

When considering scheduling, for all varieties that were transplanted in weeks 11 and 13, the quality score was greater for the later transplant date (**Table 11**) when assessed two and three WAT. However, the scores for *B.* La Paz (seed) and *B.* Santa Cruz Sunset were lower at the final assessment (9 and 7 WAT) as they had produced fewer flowers than some other varieties and were slightly stretched. Quality was generally maintained throughout the trial for *B.* Bossa Nova and *B.* Million Kisses Amour.

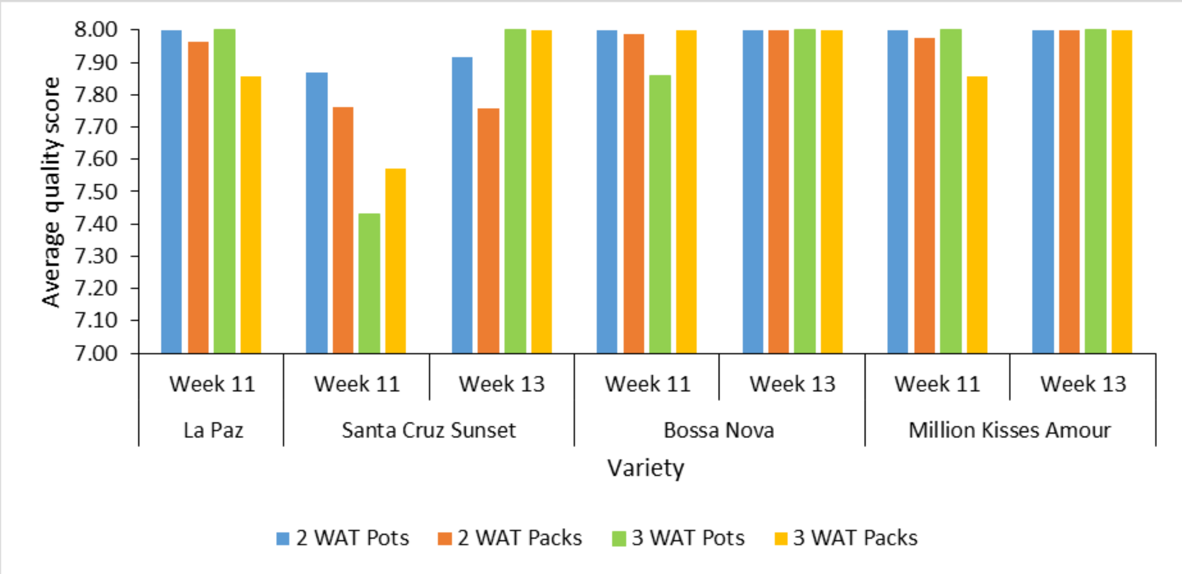


Figure 5. *Begonia boliviensis* average quality scores assessed 2 WAT (26 March and 2 April for batches 1 and 2 respectively) and 3 WAT (9 April and 16 April for batches 1 and 2 respectively) Scoring: 1 = poor, 9 = exceptional. Scoring based on number of flowers, flower colour, foliage colour, plant habit and consistency.

Table 11. *Begonia boliviensis* average quality scores, assessed by ADAS and Growers 9 WAT (for week 11 transplant) and 7 WAT (for week 13 transplant) on 13 May 2015. Green text = highest scores; red text = lowest scores.

Variety	Pots				Packs			
	Week 11		Week 13		Week 11		Week 13	
	Grower	ADAS	Grower	ADAS	Grower	ADAS	Grower	ADAS
Bossa Nova (S)	7.5	8.0	7.0	8.0	7.5	8.0	7.0	8.0
La Paz(S)	6.9	7.0	†	†	6.6	7.0	†	†
Million Kisses Amour (V)	8.3	8.0	8.0	8.0	8.3	8.0	8.0	8.0
Santa Cruz Sunset (S)	5.5	5.0	5.7	5.0	5.5	5.0	5.7	5.0

Scoring: 1 = poor, 9 = exceptional. Scoring based on number of flowers, flower colour, foliage colour, plant habit and consistency. V = Vegetative and S =Seed raised. † = plants not supplied. La Paz was not supplied for transplant in week 13

Calibrachoa

Quality scores for the *Calibrachoa* were more varied than for the *Begonia. C.* Kabloom (seed), *C.* Cabaret (vegetative) and *C.* Callie (vegetative, week 13 transplant only) all scored consistently well when assessed two and three WAT (**Figure 6**); *C.* Aloha Kona (vegetative) also scored well, although it was only supplied for transplant in week 11. The consistently high scores for *C.* Kabloom were of particular interest to growers as this was a seed raised variety.

The quality of *C.* Kabloom, *C.* Aloha Kona and *C.* Cabaret was maintained throughout the trial, and these varieties were scored more favourably when assessed 9 and 7 WAT (week 11 and 13 transplants respectively) by both growers and ADAS (**Table 12** and **Appendix 1**); analysis (Friedman test) ranked *C*. Aloha Kona highest and *C*. Crave (seed) lowest of those transplanted in week 11. Of those transplanted in week 13, *C*. Cabaret was ranked highest and *C*. Callie lowest. *C.* Crave was scored less favourably due to its habit, which appeared lax and slightly untidy when grown under this regime, compared with other varieties (Refer to Appendix 1 for images).

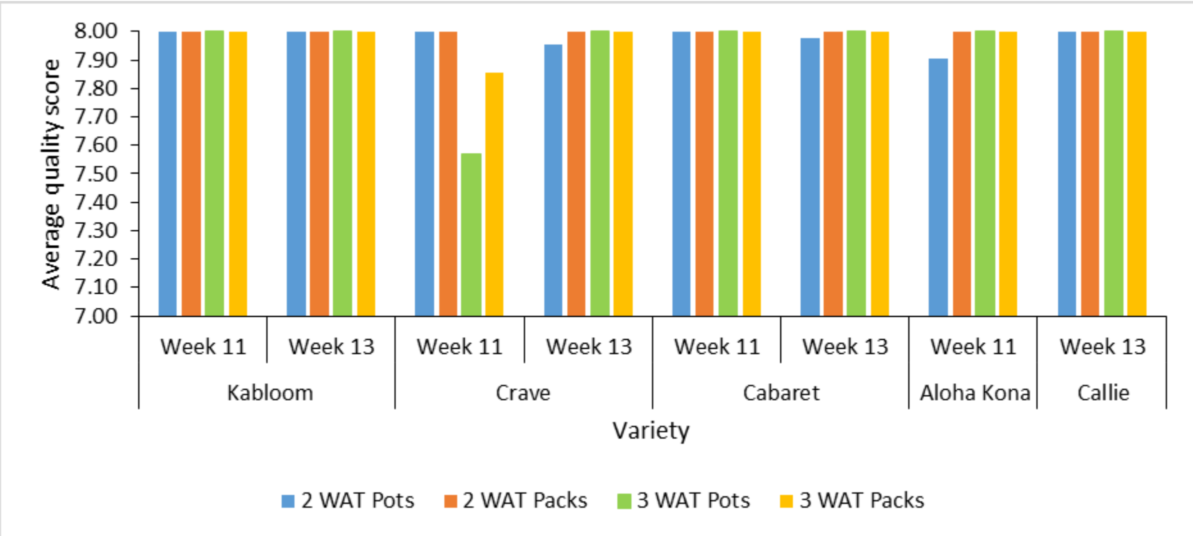


Figure 6. *Calibrachoa* average quality scores assessed 2 WAT (26 March and 2 April respectively) and 3 WAT (9 April and 16 April respectively) Scoring: 1 = poor, 9 = exceptional. Scoring based on number of flowers, flower colour, foliage colour, plant habit and consistency.

Table 12. *Calibrachoa* average quality scores assessed by ADAS and Growers 9 WAT (for week 11 transplant) and 7 WAT (for week 13 transplant) on 13 May 2015**.** Green text = highest scores; red text = lowest scores.

Variety	Pots				Packs			
	Week 11		Week 13		Week 11		Week 13	
	Grower	ADAS	Grower	ADAS	Grower	ADAS	Grower	ADAS
Aloha Kona (V)	7.6	8.0	†	†	7.6	8.0	†	†
Cabaret (V)	7.6	8.0	7.2	7.0	7.4	7.0	7.0	7.0
Callie (V)	†	†	5.2	6.0	†	†	5.4	6.0
Crave (S)	7.2	7.0	6.2	6.0	7.2	7.0	6.0	6.0
Kabloom (S)	7.4	8.0	6.8	7.0	7.4	8.0	6.8	7.0

Scoring: 1 = poor, 9 = exceptional. Scoring based on number of flowers, flower colour, foliage colour, plant habit and consistency. †= plants not supplied. Callie and Aloha Kona were not supplied for transplant in weeks 11 and 13 respectively. V = Vegetative and S =Seed raised.

Plant height

Plant height was recorded at two and three WAT to provide an indication of vigour, to clarify the variation between plants grown in pots and packs, and the effect of transplant date.

Begonia boliviensis

Across all *Begonia* varieties, plants grown in packs were generally larger than those in pots (**Figure 7**). For most varieties, those transplanted in week 13 were taller than those transplanted in week 11. However, for *B*. Bossa Nova, whilst the converse was true, there was less difference in height between the two transplant dates, suggesting that this variety may be less responsive to the variation in temperature and environment experienced during this trial, and therefore easier to manage commercially, and this may be of particular interest as this is a seed grown variety.

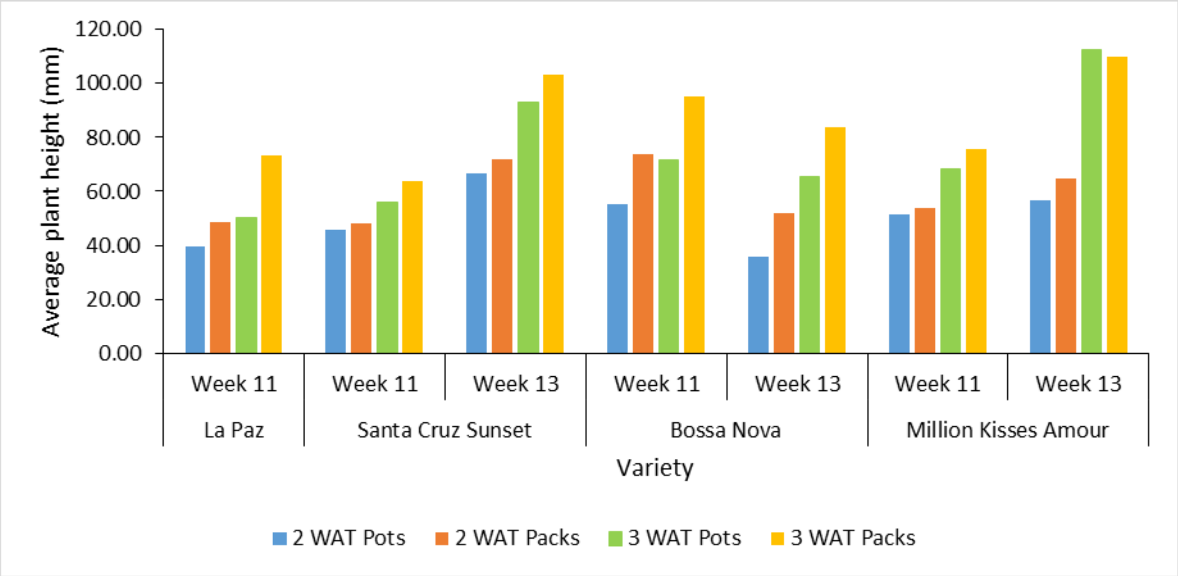


Figure 7. *Begonia boliviensis* average height assessed 2 WAT (26 March and 2 April respectively) and 3 WAT (9 April and 16 April respectively)

Calibrachoa

The trends in plant height recorded for the *Begonia,* were not mirrored by the *Calibrachoa,* with no consistency in size difference between pots and packs (**Figure 8**). However, week 13 transplants were larger than week 11 transplants for all varieties. *C.* Kabloom (seed) showed greatest consistency in plant height between container and transplant date. As for *B.* Bossa Nova, for *C.* Kabloom the height difference recorded for the two transplant dates was small, suggesting that this variety may be less responsive to the variation in temperature and environment experienced during this trial, therefore this variety may be easier to manage commercially.

Cost assessment

- An assessment of inputs identified that in this trial, for both the *Begonia* and *Calibrachoa* there was no difference between varieties; for example fungicides and growth regulators were applied to all varieties of *Calibrachoa* and similarly, fungicides were applied to all varieties of *Begonia* (**Table 1**). Costs were also influenced by the variety, tray / plug size, and delivery costs. Some suppliers included the delivery cost in the price per plug and were unable to provide price net of delivery. Smaller plugs (more plugs per tray) were less costly but the plants achieved a similar plant size as those from larger plugs within the timeframe of this trial. Royalties are not payable on seed-raised varieties which suggests that overall they ought to be cheaper than vegetative varieties. Whilst this was borne out for the *Calibrachoa*, it was less clear for the *Begonia* as the plug price was inclusive of delivery.

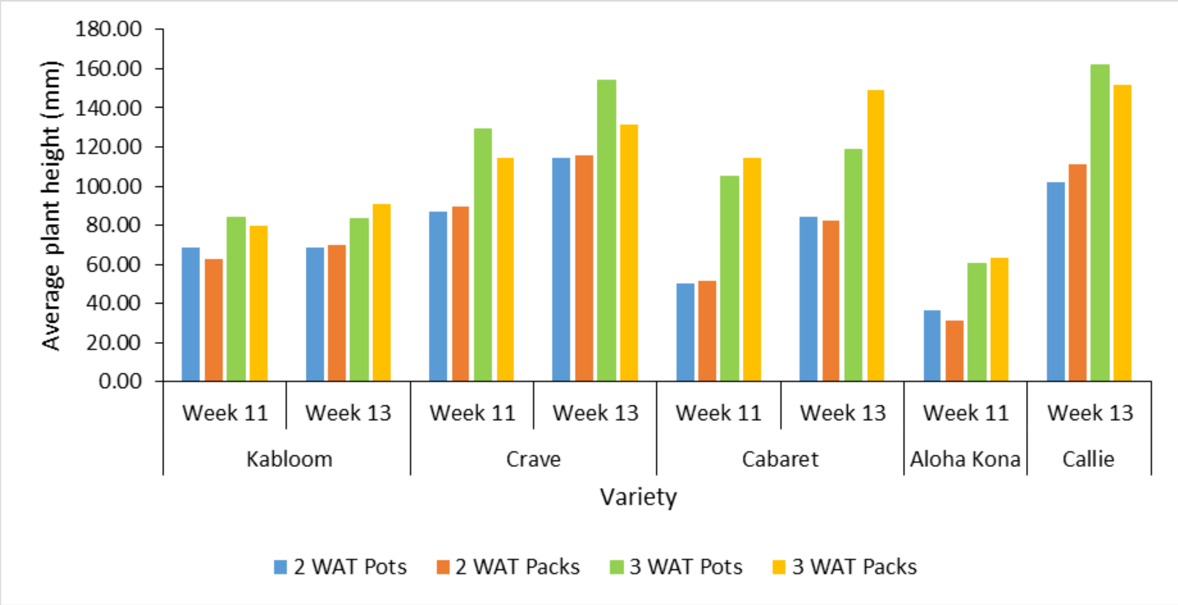


Figure 8. *Calibrachoa* average height assessed 2 WAT (26 March and 2 April respectively) and 3 WAT (9 April and 16 April respectively)

Table 13. Seed vs cutting varieties of *Begonia boliviensis* and *Calibrachoa* production cost comparison. *Exclusive of royalties. †Inclusive of delivery costs. S = seed; v = vegetative.

Variety	Tray size	Cost (p/plug)*	Royalty (p/plug)	Total (p/plug)
Begonia Bossa Nova (s)	84	36.50	0	36.50
Begonia Santa Cruz Sunset (s)	84	53.95†	0	53.95†
Begonia La Paz (s)	180	36.00	0	36.00
Begonia Million Kisses Amour (v)	66	52.11†	6.2	58.31†
Calibrachoa Kabloom (s)	84	32.13†	0	32.13†
Calibrachoa Crave (s)	84	32.13†	0	32.13†
Calibrachoa Cabaret (v)	84	32.13†	4.1	36.23†
Calibrachoa Aloha Kona (v)	128	20.50	4.1	24.60
Calibrachoa Callie (v)	128	30.00	3.7	33.70

Objective 2: Temperature effect on days to flowering

It was not possible to replicate treatment areas, therefore statistical analysis of the results between treatments was not appropriate. Analysis within each of the treatments compares the effect of the environment applied on plant growth and development.

The trial was not affected by any pests or diseases.

Root development

For each species, the plugs had well developed healthy root systems that were even across the plug tray, with many fine root hairs.

Plant quality

At transplant, all plugs for all five species were of high quality, with scores of 8.0 across all species. There was no evidence of any pest or disease damage, and all plugs within each tray were of a similar height, with approximately the same number of leaves present.

Throughout the trial, the plants remained healthy and plant quality continued to be high. When the plants were assessed three WAT, the *Petunia* growing in T1 (16°C) appeared less branched than those under higher temperatures. This remained the case for the duration of the trial.

Plant height

Pre-transplant, plant height was even across all plugs for each species. Plant height recorded three WAT identified differences between the three treatment areas (**Figure 9**). For all species, plants were shorter under T1 (16°C). However, there were differences in plant response to temperature; French marigold, *Salvia* and *Verbena* were taller under T2 (18°C) than T3 (19°C), but conversely *Dianthus* and *Petunia* were taller under T3 (19°C) than T2 (18°C). Plant quality was maintained for all species under the various treatments.

Date of first flowering, predicted vs actual flowering time

FlowersOnTime is acknowledged to predict production times with a typical variation of ±7 days, and for the French marigold and *Salvia splendens*, the time to flower was generally within this tolerance level, even though the temperatures for this trial were at the top end of the range used to construct the FlowersOnTime tool (**Figure 10** and **Appendix 2**). For *Dianthus, Petunia* and *Verbena*, the flowering time was close to but not within the +7 days tolerance level.

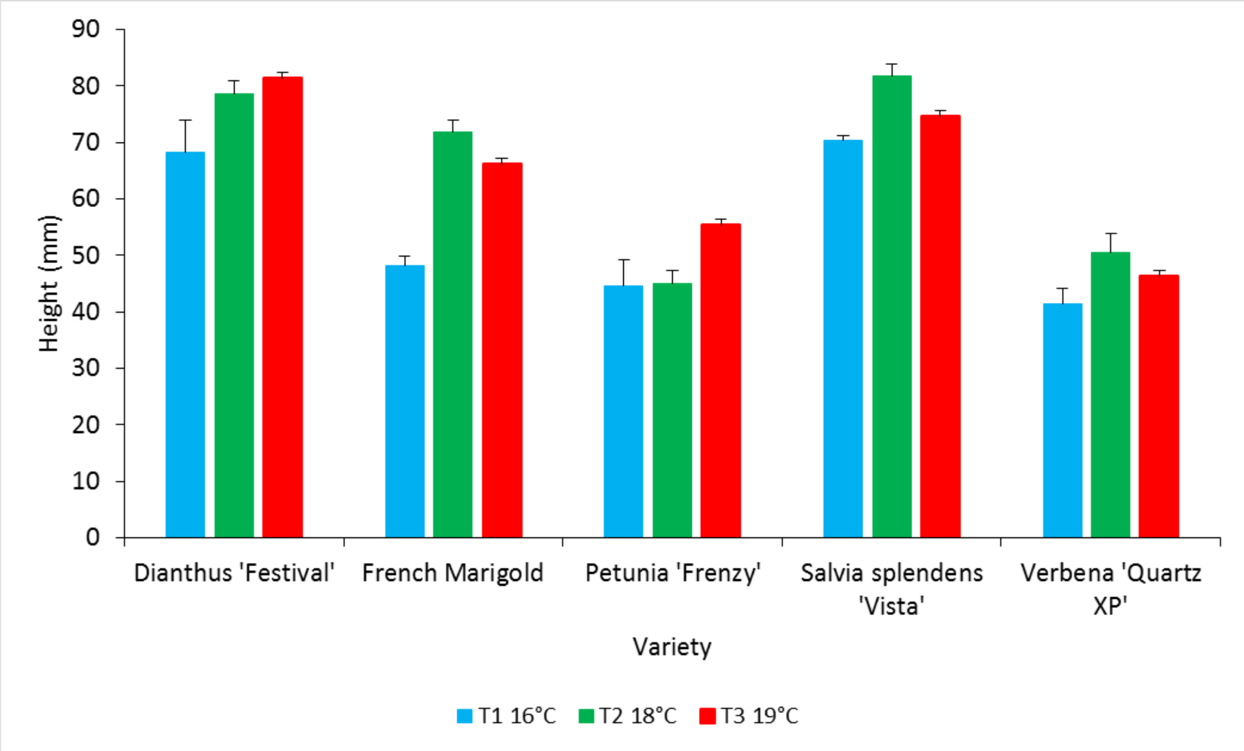


Figure 9. Average plant height for each species within each treatment area, 3 WAT

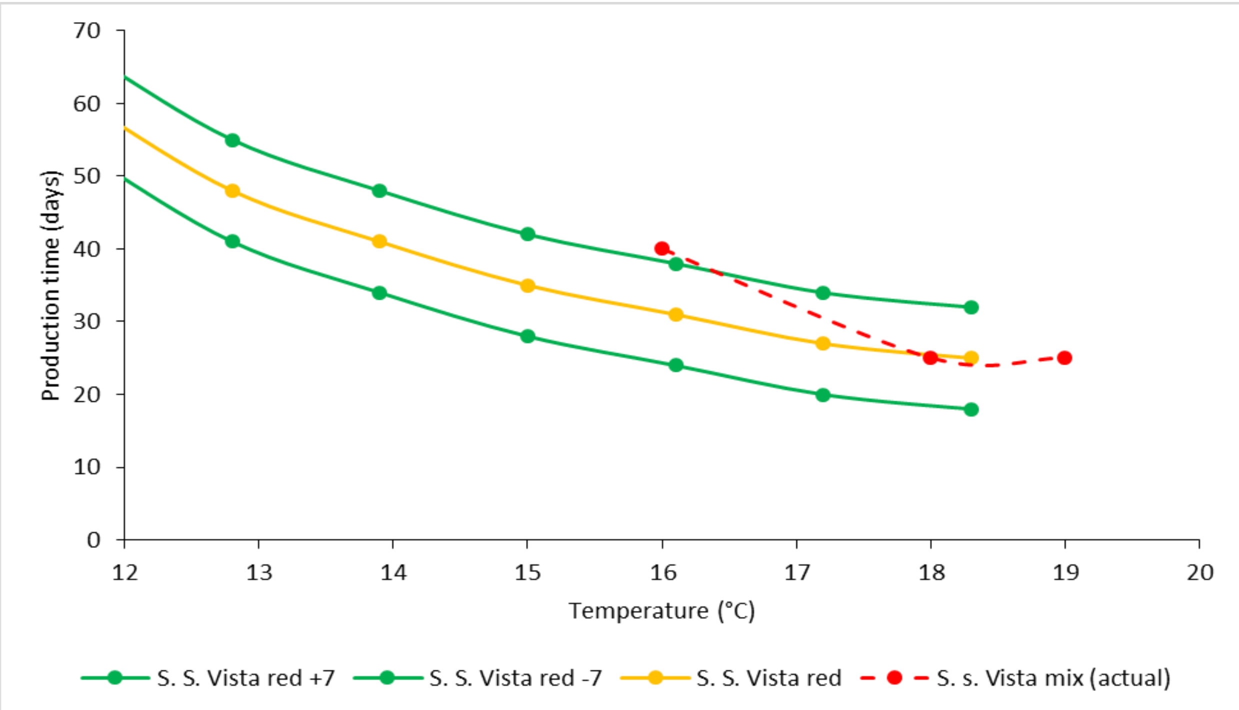


Figure 10. FlowersOnTime prediction vs actual flowering time – *Salvia splendens* Vista mix

For most of the species, there was a notable difference in flowering time between the three treatment areas (**Table 14**), particularly with *Petunia* where plants grown at 19°C came into flower 15 days earlier than those grown at 16°C. This was also the case for *Salvia*, with plants growing at both 18°C and 19°C coming into flower earlier than those grown at 16°C. For *Dianthus,* there was no difference in flowering time between 18°C and 19°C, and for French marigold, plants grown at both 16°C and 18°C came into flower at the same time. For *Verbena* flowering time was unaffected by temperature under these conditions.

Table 14. Number of days from transplant to first flower. Values in brackets are the number of days to first flower as predicted by the FlowersOnTime tool

Variety	T1: 16°C	T2: 18°C	T3: 19°C*
Dianthus 'Festival'	40 (26)	32 (23)	32 (n/a)
French Marigold	25 (26)	25 (23)	19 (n/a)
Petunia 'Frenzy'	40 (24)	32 (20)	25 (n/a)
Salvia splendens 'Vista'	40 (31)	25 (25)	25 (n/a)
Verbena 'Quartz XP'	40 (26)	40 (23)	40 (n/a)

*This temperature was outside the range of the FlowersOnTime tool

Number of flowers

The trial was assessed six WAT, and the number of flowers per plot were recorded (**Figure 11**). As expected, there was a greater number of fully open flowers within T3 (19°C), compared with the cooler temperatures (**Figure 12**). The difference was more notable with the *Petunia*, with 48 more flowers in T3 compared to T1.

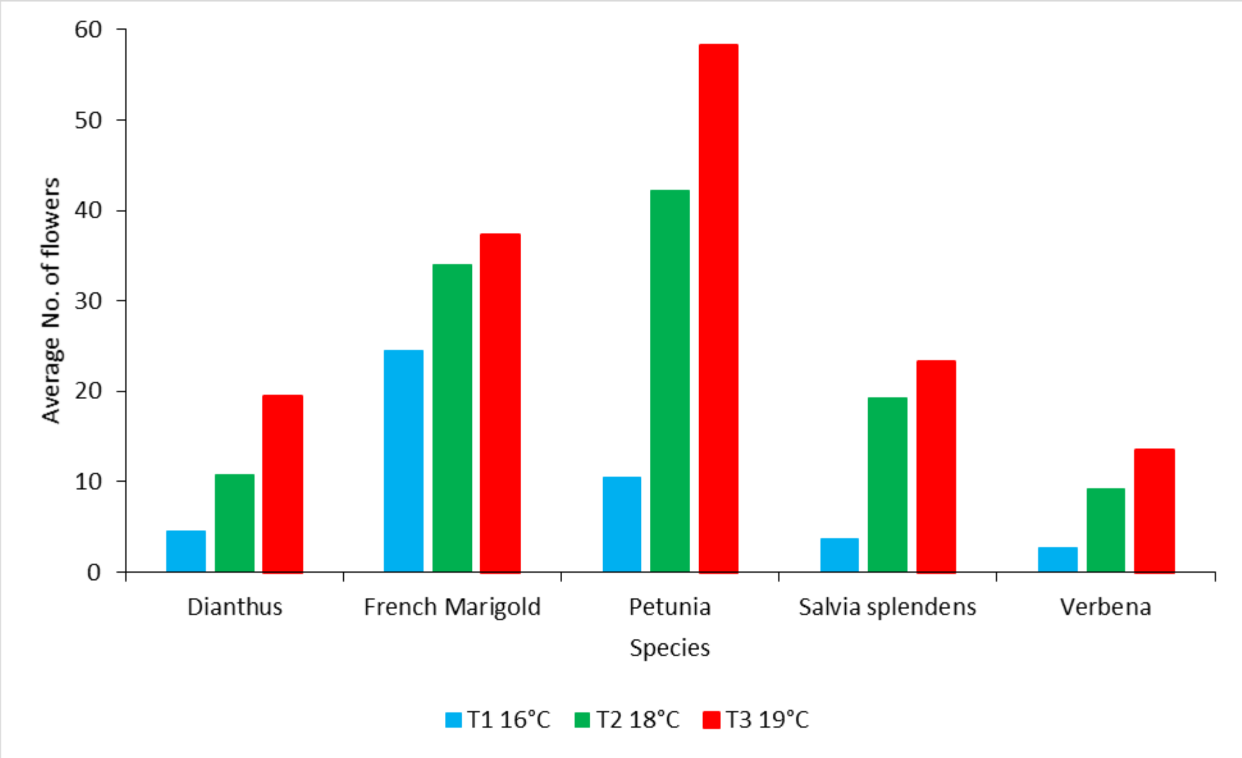


Figure 11. Number of flowers per plot six WAT

Figure 12. Treatment areas six WAT

Objective 3: Demonstration of spectral filters (film)

Plants were monitored throughout the trial for pests and diseases. One treatment of Gazelle (acetamiprid, 0.25 g/L water) was applied to all varieties to control aphid, which was present mainly on the *Viola* Sorbet XP at that time.

It was not possible to replicate treatment areas and the treatment structures used were diverse (size, air volume etc.), therefore statistical analysis of the results between treatments was not appropriate. Analysis within each treatment compares the effect of the environment (temperature, humidity, light quality and light transmission) provided by each spectral filter on a range of plant species.

Temperature and humidity

Temperature and humidity were monitored throughout the trial (**Appendix 3**). It was generally warmest under the untreated glass, and coolest under the SmartBlue tunnels (new and old), although it was also generally cooler under the Lumisol and Luminance tunnels treatments than the glass. Humidity levels appeared to be less affected by the spectral filters, being similar under all treatments.

Plant quality

The quality of the plugs supplied was good, with all plants having healthy roots evenly distributed throughout the plug, and even plant height within species.

Plant quality was generally good (score >7, commercially acceptable) throughout the trial (**Figure 13**). Where lower scores were achieved this was generally due to uneven plant height within treatment plots, however the *Salvia vista* was affected by scorch in all plots under the Lumisol treatment. None of the other varieties were affected by scorch.

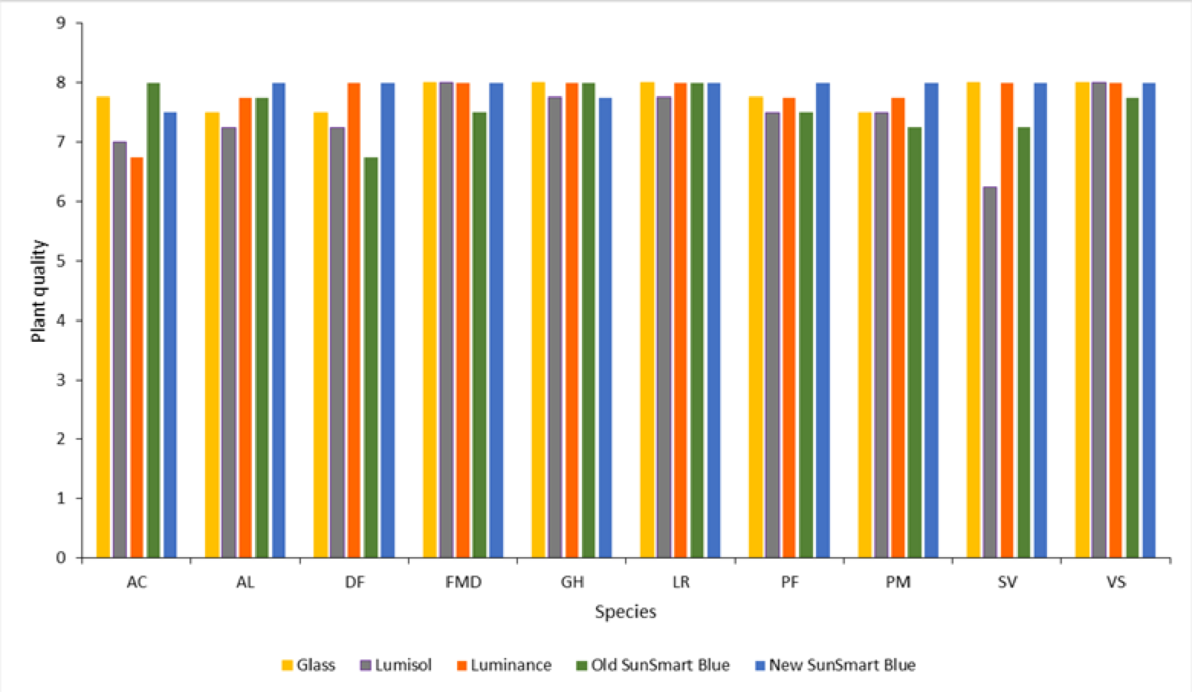


Figure 13. Plant quality, 18 June 2015, 11 and 6 WAT (Geranium and other spp. respectively). Species: AC-*Ageratum* Champion, AL-*Antirrhinum* Liberty, DF-*Dianthus* Festival, FMD-French Marigold Durango, GH-Geranium Horizon, LR-*Lobelia* Regatta, PF-*Petunia* Frenzy, PM-Pansy Matrix, SV-*Salvia* Vista and VS-*Viola* Sorbet XP

Plant growth

Plant height, recorded when the plants were transferred into the treatments and at the end of the trial, was used to calculate plant growth (**Figure 14**). Whilst statistical analysis has not been used to compare differences between treatments, for the majority of plant varieties included the light diffusing filters Luminance resulted in more compact plants than those produced under glass; the exceptions to this were *Dianthus* Festival and *Lobelia* Regatta, which were more compact under the untreated glass and the new SunSmart Blue tunnel, respectively. Growth was generally greater under the new SunSmart Blue tunnel than the old tunnel, *Pansy* Matrix, *Dianthus* Festival and *Geranium* Horizon being the exceptions.

The variation in plant growth response to the various treatments is clearly demonstrated by these results (**Figure 14**), where the greatest extension growth produced by the varieties *Antirrhinum* Liberty, French marigold Durango and *Viola* Sorbet XP resulted from different treatrments in each case i.e. under Glass, New SunSmart Blue and Luminance (respectively). A number of varieties were less sensitive to the environment, producing similar growth under all treatments, for example *Ageratum* Champion, Geranium Horizon and *Salvia* Vista.

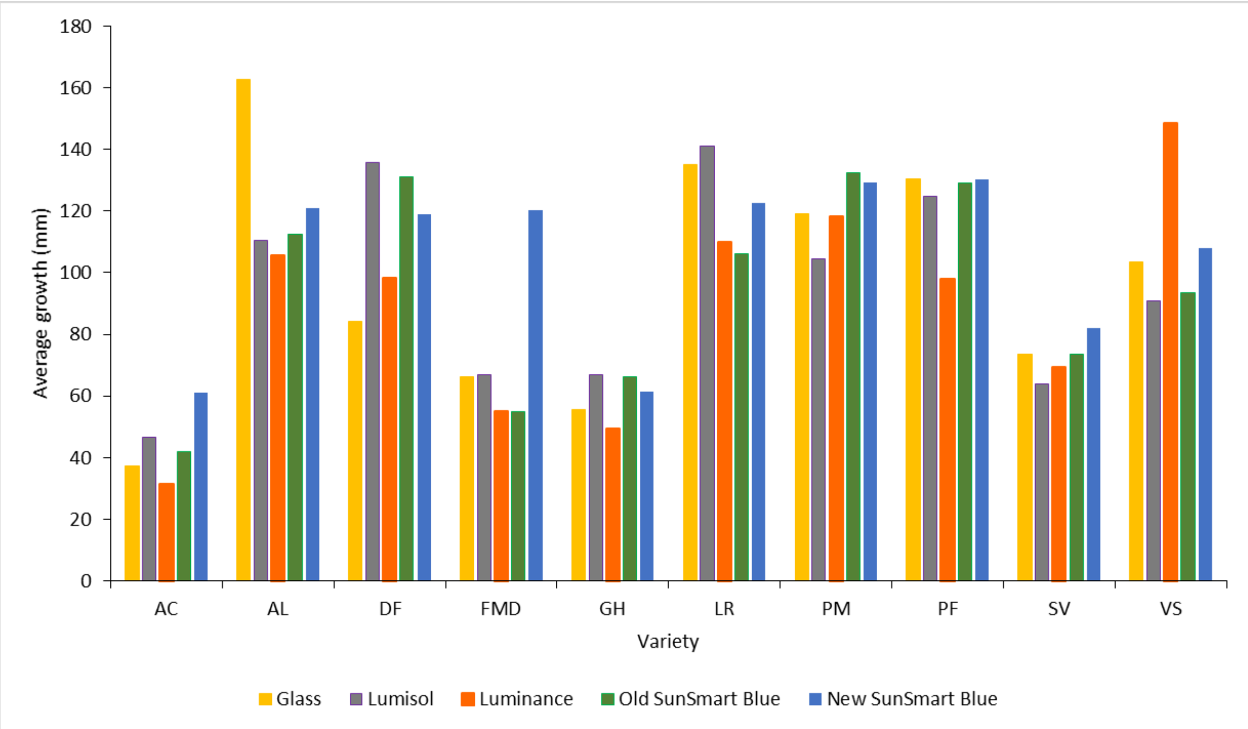


Figure 14. Average plant growth. 18 June 2015, 11 and 6 WAT (Geranium and other spp. respectively). Species: AC-*Ageratum* Champion, AL-*Antirrhinum* Liberty, DF-*Dianthus* Festival, FMD-French Marigold Durango, GH-Geranium Horizon, LR-*Lobelia* Regatta, PM-Pansy Matrix, PF-*Petunia* Frenzy, SV-*Salvia* Vista and VS-*Viola* Sorbet XP

Number of plants with fully open flowers

Flowering time was heavily variety dependent, with numbers ranging from no open flowers by the final assessment (*Antirrhinum* Liberty) to all plants (48) having open flowers by the 5th June assessment (*Viola* Sorbet XP) (Figure 15); *Salvia* Vista only produced flowers under the glass treatment. For the majority of varieties, flowering was advanced under glass (**Figure 15** and **Figure 16)**, and the two SunSmart Blue tunnels appeared to delay flowering, with fewer plants in flower than other treatments on all assessment dates. The majority of species started to flower sooner under the old SunSmart Blue tunnel than the new tunnel. Although variable across the species, flowering under the two light diffusing tunnels (Lumisol and Luminance) was generally advanced under the Luminance treatment.

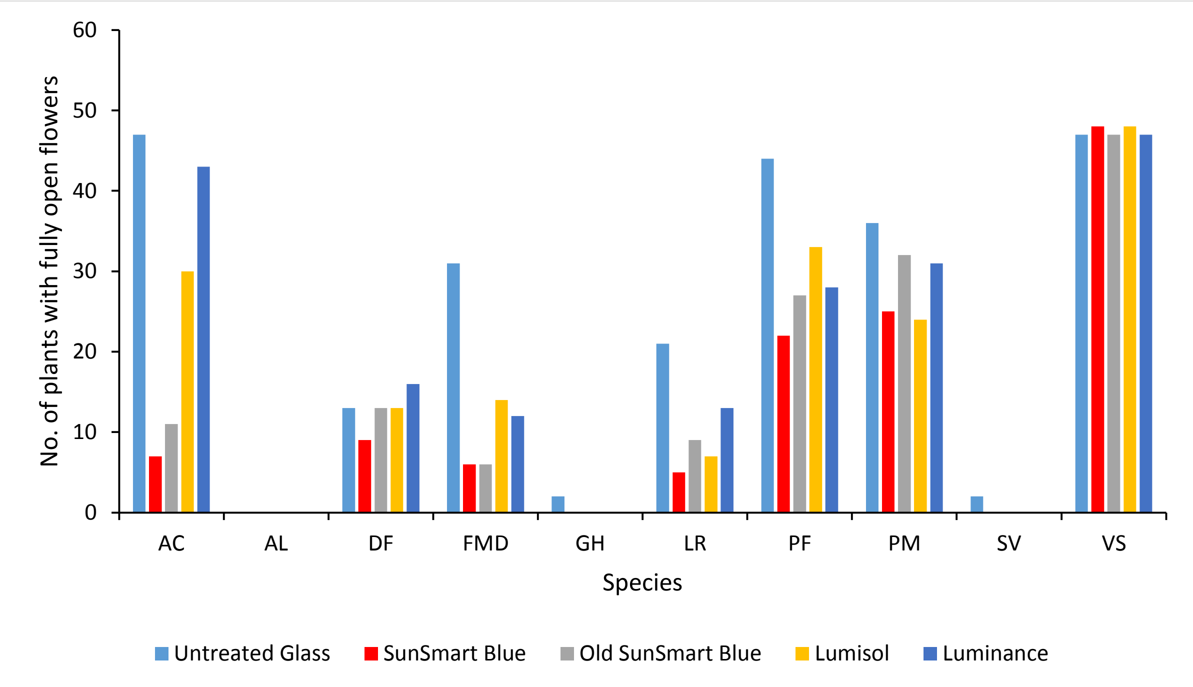


Figure 15. Number of plants with fully open flowers 9 WAT (Geranium) and 4 WAT (all other varieties). Species: AC-*Ageratum* Champion, AL-*Antirrhinum* Liberty, DF-*Dianthus* Festival, FMD-French Marigold Durango, GH-Geranium Horizon, LR-*Lobelia* Regatta, PF-*Petunia* Frenzy, PM-Pansy Matrix, SV-*Salvia* Vista and VS-*Viola* Sorbet XP

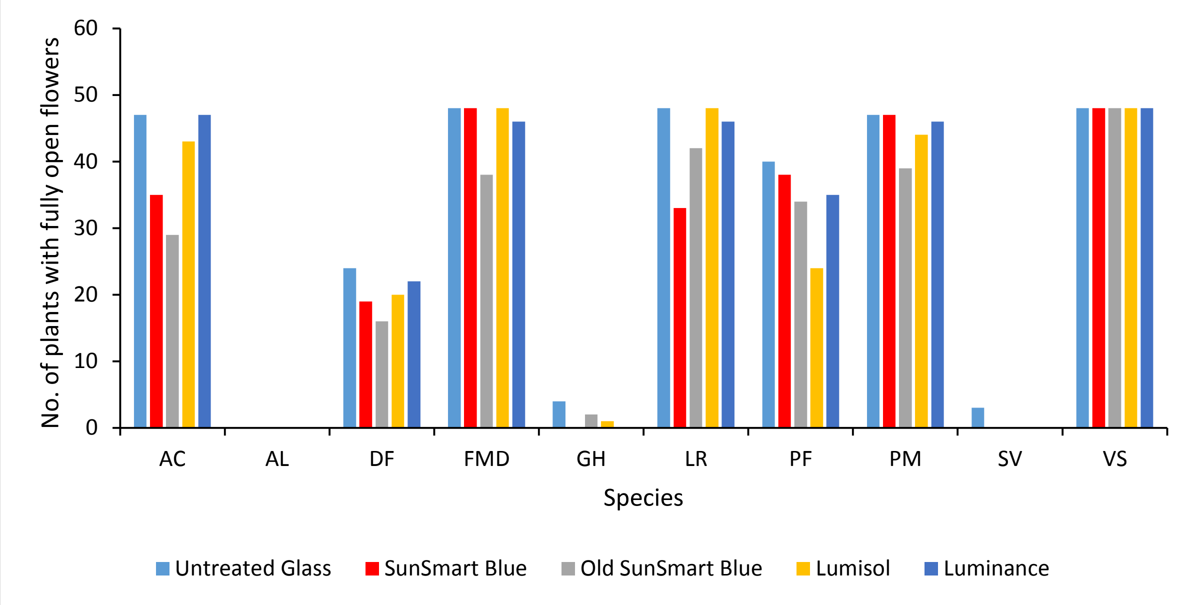


Figure 16. Number of plants with fully open flowers 10 WAT (Geranium) and 5 WAT (all other varieties). Species: AC-*Ageratum* Champion, AL-*Antirrhinum* Liberty, DF-*Dianthus* Festival, FMD-French Marigold Durango, GH-Geranium Horizon, LR-*Lobelia* Regatta, PF-*Petunia* Frenzy, PM-Pansy Matrix, SV-*Salvia* Vista and VS-*Viola* Sorbet XP

Light transmission and spectra

The spectrum of sunlight is shown in **Figure 17** (black line). The mean PAR intensity of full sun during the measurement periods was 2224 µmol m^{-2} s^{-1}, consistent with the maximum solar radiation expected at this location in sunny conditions. Inside the glasshouse the PAR light intensity was reduced by 21% and the UVA light intensity was reduced by 38%. The spectrum within the glasshouse (**Figure 17**, green line) was similar in shape to that of full sun but when the light transmittance of the glasshouse was determined (**Figure 18**) it was clear that UV light with wavelengths less than 350nm are absorbed by the glass. Within the PAR region of the spectrum slightly more green light (81%) was transmitted than red (80%) or blue (76%) light (**Table 15** and **Figure 18**). With the screens in the glasshouse closed the total light inside the glasshouse was greatly reduced with only 15% of the available sunlight reaching the plants (**Table 15**).

Light diffusing plastics

Light spectra were assessed in two polytunnels with light diffusing plastic. One was clad with Lumisol and one was clad with Luminance. The light spectrum under the two plastics was similar (**Figure 19**) though some differences, especially at shorter wavelengths, were observed. In the far-red region of the spectrum both plastics transmitted a similar amount of light (76%, **Table 15**). As wavelength decreased, absolute transmittance decreased and the differences in transmittance between the two plastics increased (**Figure 20**). In the red and green regions of the spectrum, Luminance transmitted 3% more light than Lumisol. In the blue region of the spectrum Luminance transmitted 4% more light than Lumisol and in the UVA region of the spectrum Luminance transmitted 9% more light than Lumisol.

SunSmart Blue plastic

Light measurements were performed in two polytunnels clad with SunSmart Blue plastic. One tunnel was clad with new plastic and one was clad with older plastic. These plastics transmitted approximately 40% of the available PAR light. The light spectra within the two tunnels was largely similar (**Figure 21**) with proportionally greater transmission in blue (~65%) than green (51%), red (21%) or UVA (21%) region of the spectrum (**Table 15** and **Figure 22**). The older blue plastic transmitted slightly more red and UVA light than the new plastic which is consistent with slight sun damage of the plastic and/or pigments within the plastic.

Table 15. The mean light intensity measured outside and within each trial area under conditions of full sun.

Colour	**PAR**	**UVA**	**Blue**	**Green**	**Red**	**Far red**
Wave band / nm	**400-700**	**320-400**	**400-500**	**500-600**	**600-700**	**700-800**
	Mean photon irradiance / µmol m^{-2} s^{-1}					
Sun	2224	123	572	795	858	752
Glass	1760	76	433	641	685	583
Glass + Screen	339	13	82	124	134	123
Lumisol	1556	71	376	562	618	568
Luminance	1632	82	402	588	643	574
New SunSmart Blue	956	26	372	406	178	298
Old SunSmart Blue	982	28	355	417	210	292
	% transmission					
Glass	79	62	76	81	80	78
Glass + Screen	15	10	14	16	16	16
Lumisol	70	57	66	71	72	76
Luminance	73	66	70	74	75	76
New SunSmart Blue	43	21	65	51	21	40
Old SunSmart Blue	44	22	62	52	25	39

*Photon irradiance: a measurement of the number of photons incident on a surface

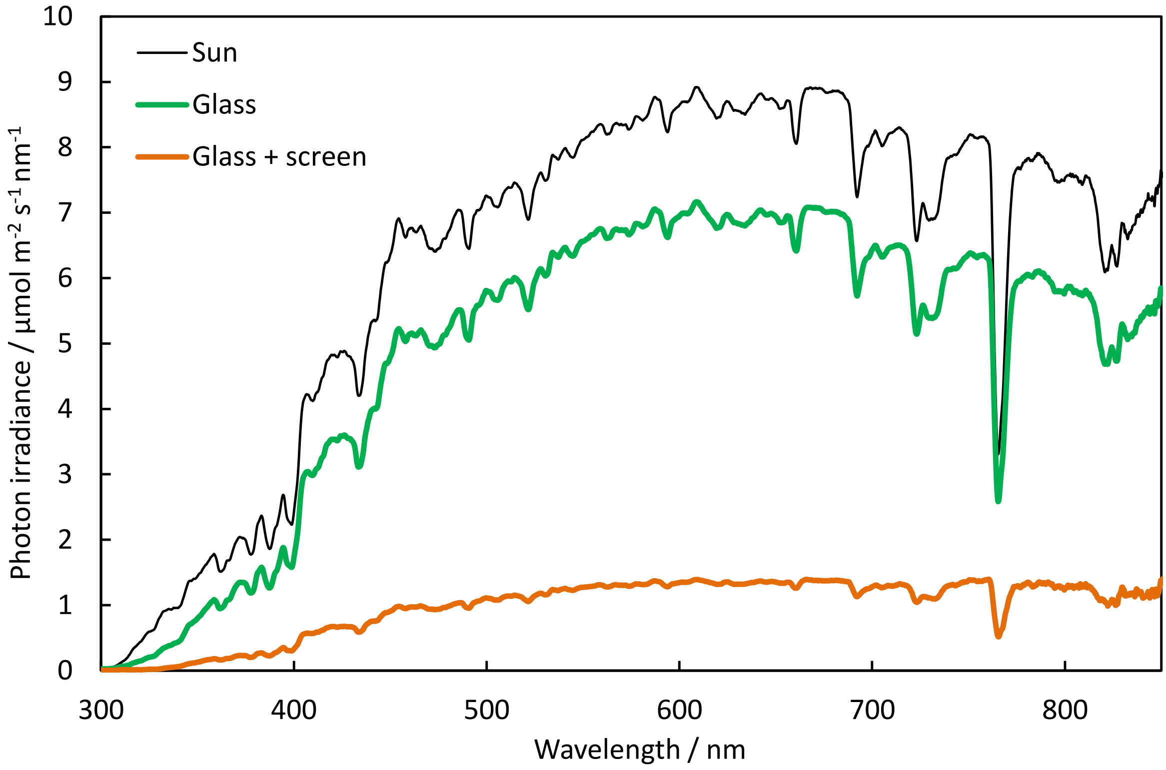


Figure 17. Light spectra measured outside in full sun (Sun), inside the glasshouse when the screen were open (Glass) and when the screens were closed (Glass + Screens) – 22 June 2015

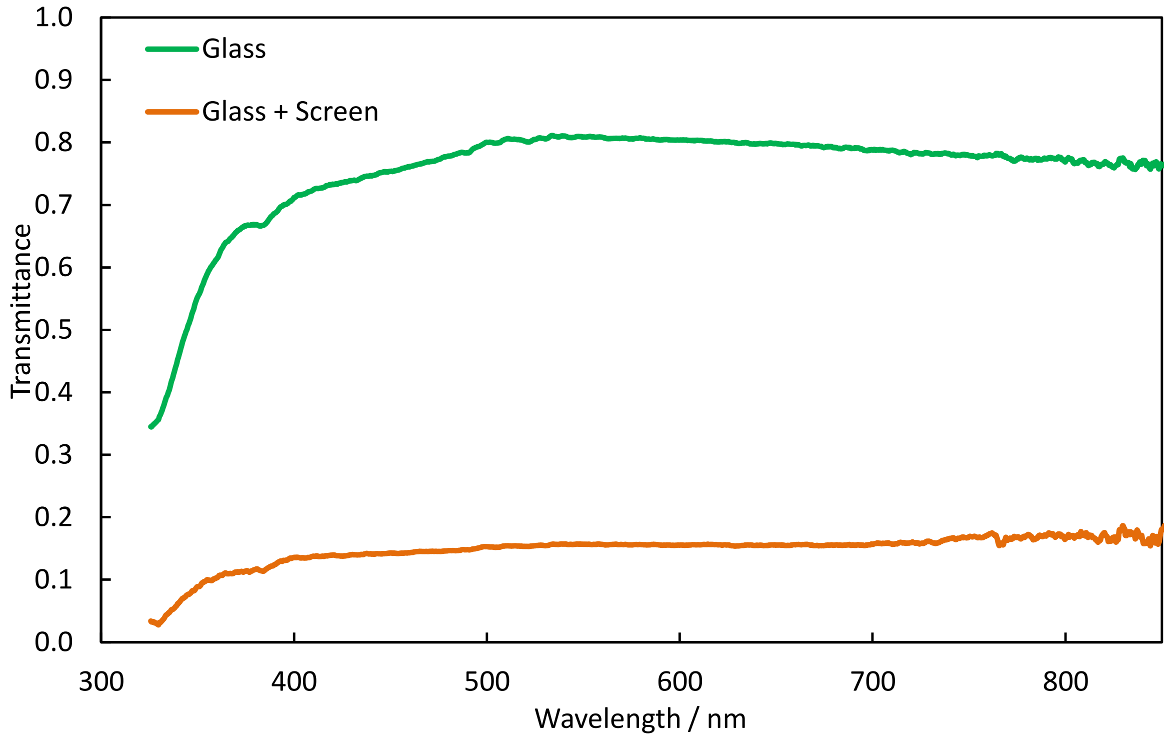


Figure 18. Transmittance spectra of the glasshouse with the screens open (glass) and closed (glass + screens) – 22 June 2015

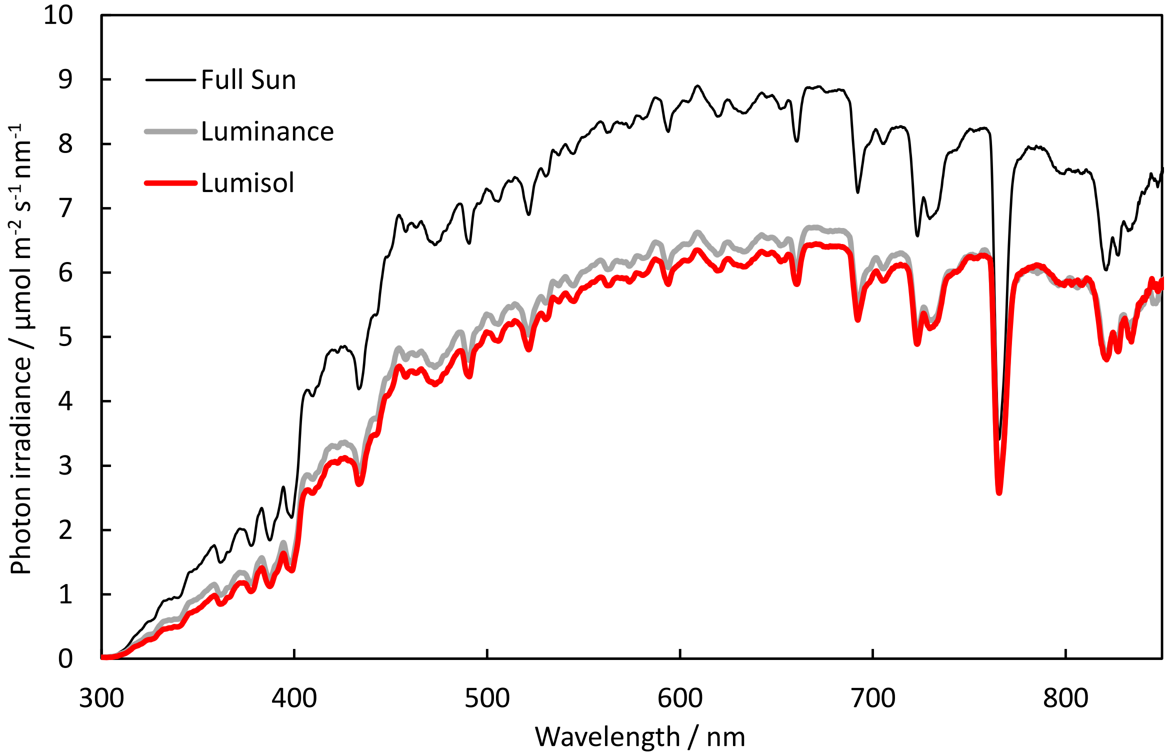


Figure 19. The measured spectra in the polytunnels covered with Luminance and Lumisol diffusing plastics. The spectrum of full sun is shown for comparison – 22 June 2015

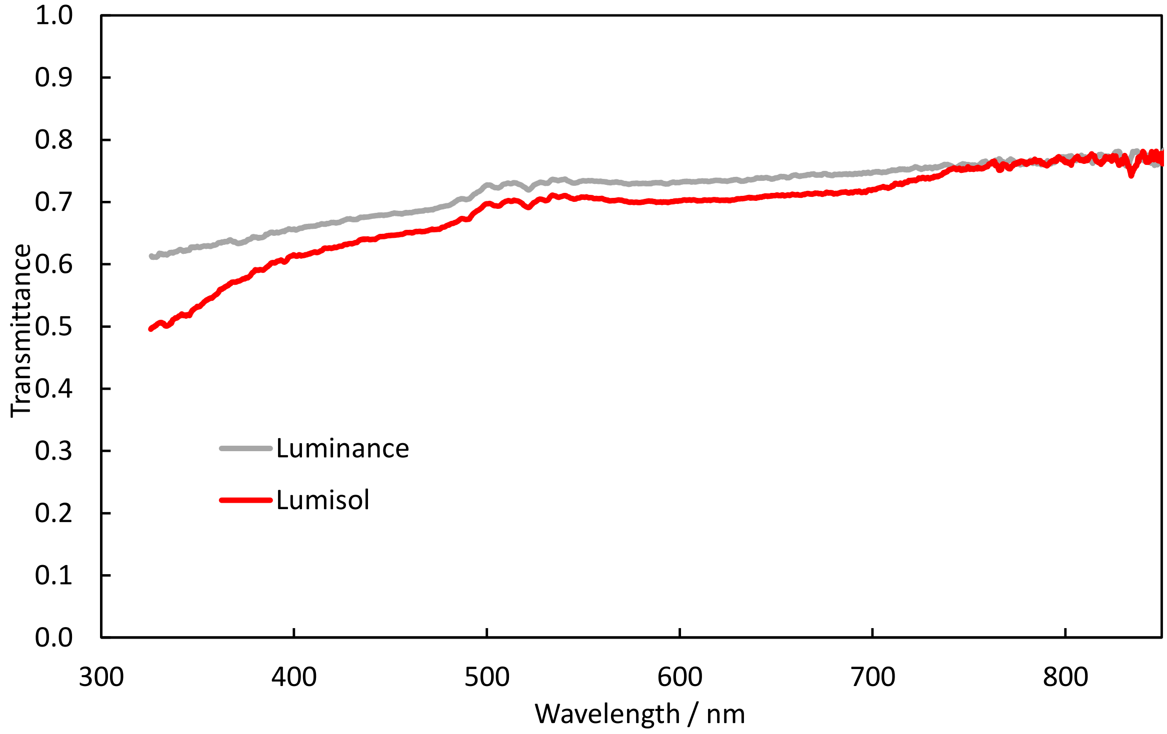


Figure 20. Transmittance spectra of Luminance and Lumisol clad polytunnels – 22 June 2015

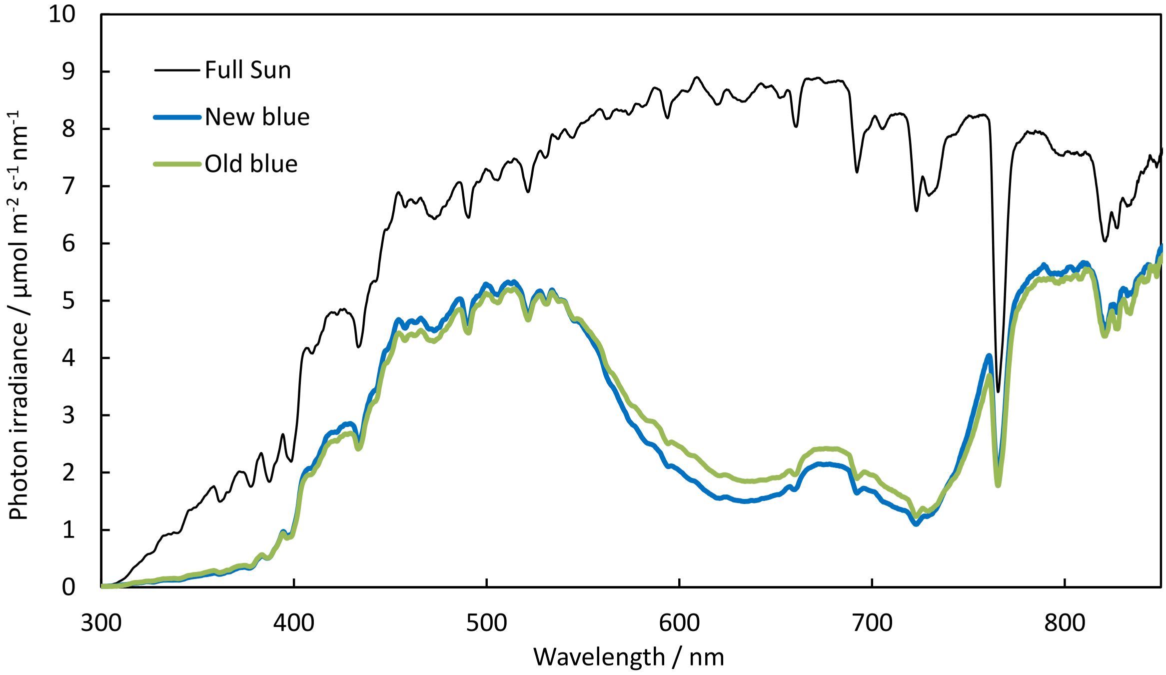


Figure 21. The measured spectra in the polytunnels covered with new and old SunSmart Blue plastics. The spectrum of full sun is shown for comparison – 22 June 2015

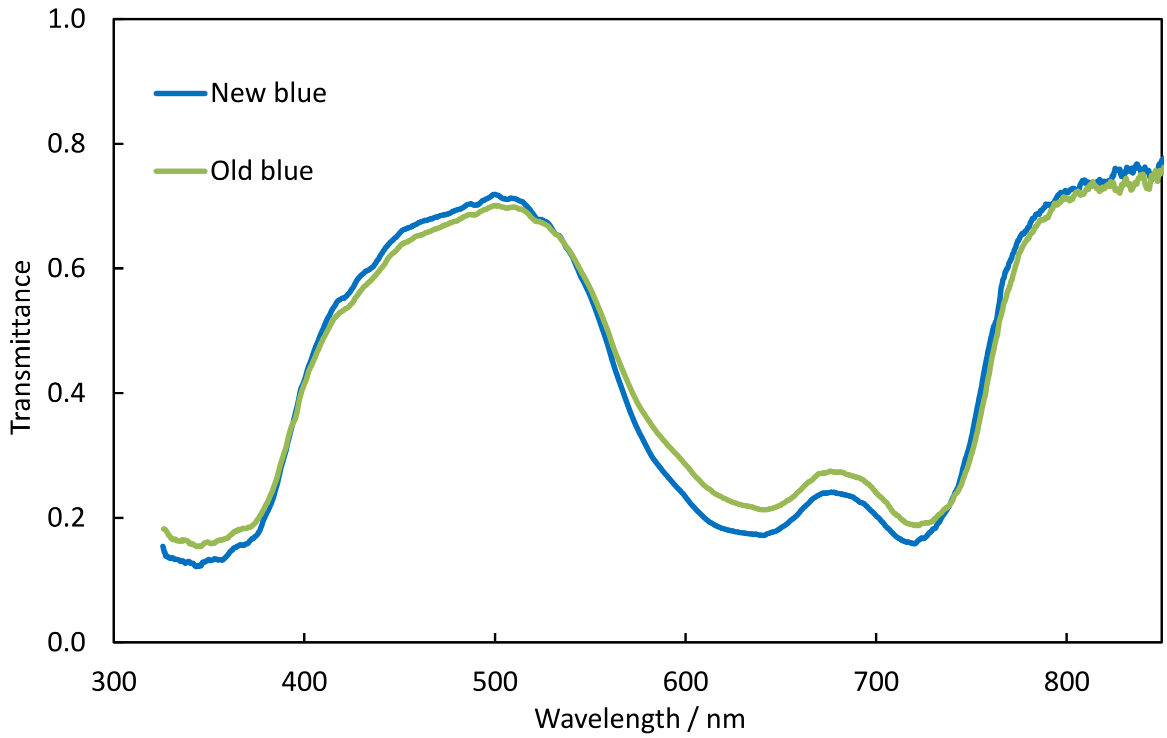


Figure 22. Transmittance spectra of new and old SunSmart Blue clad polytunnels – 22 June 2015

Discussion and Conclusion

Objective 1: Seed vs cutting varieties of Begonia boliviensis and Calibrachoa

B. Million Kisses Amour, the sole vegetative *Begonia* included in this trial, did achieve high quality scores and was favoured by growers. However, there were also promising seed-raised varieties. *B.* Bossa Nova in particular scored well for quality – particularly for the later transplant date – and there was less difference in plant height across the two transplant dates suggesting it may be less responsive to variation in the environment than other varieties.

For the *Calibrachoa, C*. Kabloom (seed raised) scored consistently well for quality, showed less variation in height (2 and 3 WAT), and was scored favourably by growers. However, *C.* Aloha Kona and *C.* Cabaret did also generally achieve good scores, including the highest grower scores for week 11 and 13 transplants respectively.

For this trial, it was necessary to provide the same inputs, for example water volume, to all varieties to allow comparisons to be made, and this may have affected quality in some varieties that favour a different regime. Similarly, whilst the *C.* Kabloom and *C.* Aloha Kona produced in this trial were compact and well branched, other varieties (e.g. *C*. Crave or *C*. Callie) may require more pinching, particularly if the production time is protracted through transplanting into larger containers or hanging baskets. Growers will need to select varieties and fine tune inputs to suit their own site and production regime. However, this trial suggests that the new seed-raised varieties of both *Begonia boliviensis* and *Calibrachoa* should compete well against vegetative varieties.

Objective 2: Temperature effect on days to flowering

For all five bedding plant species, the number of days to flower decreased with increasing temperature, except for the *Verbena* Quartz XP, which was not responsive within the temperature range (16–19°C). This suggests that application of heat (or cool) will not influence flowering time and reflects experience that *Verbena* Quartz XP tends to flower evenly through the season. For all species tested, flower number increased with temperature under these conditions. However, as there was no replication of temperature zones, the statistical significance of these results cannot be established.

When the actual flowering times for all five species were compared with the predicted flowering times given by the FlowersOnTime model, two of the species fell within the ±7 days tolerance; French marigold and *Salvia splendens*. For *Verbena*, there was no difference in flowering time between any of the temperature treatments, which may reflect its ability to flower evenly through the season.

These results suggest that there may be potential to use FlowersOnTime under UK conditions for some varieties, but the model may require some refinement to account for different production temperatures used in the UK. Further testing using a wider range of plant species under cooler conditions would confirm any scope to use FlowersOnTime to predict production time under UK conditions, however consideration would need to be given to if the $\pm$7 days tolerance is acceptable or too wide.

It was originally considered that this tool may be useful to growers during cool seasons, particularly to predict flowering, so that growers could achieve marketing with minimum additional heat input. This scenario would be of most benefit to those growers with a specific marketing date as opposed to providing plants ready for marketing throughout the season.

An alternative use may be to use the tool to calculate transplant dates, for example if growing at a set temperature suitable for the crop, or if growing early season plants over a longer period when space is not at a premium. It may also be useful to consider determination of plant maturity differently, for example by measuring days to pack/pot cover, a set number of flowers per unit or buds with colour.

The UK model ((Pearson *et al.,* 1993; Pearson, 1996; and Pearson, 1997) was based on a more limited range of seven of the main bedding species (*Antirrhinum*, Geranium, *Impatiens*, Marigold, *Petunia*, Pansy and *Salvia*). The model was designed to predict the time to flowering and the quality of plants under a range of environmental conditions; this included a number of sowing date schedules for Pansy, Geranium and *Petunia* grown at a range of temperatures. Subsequent work integrated production (e.g. pots, labour data, spacing, propagation) and financial (overhead and variable costs and sale prices) parameters into the model. This approach provided the grower with the opportunity to test the effect of any changes to the production regime on profitability. However, the model is currently unavailable and would need to be reviewed in terms of current practices and costs.

Objective 3: Demonstration of spectral filters (film)

Of the light diffusing spectral filters (Lumisol and Luminance), Luminance generally produced more compact plants than those produced under glass, although with some variation between species. Plant quality was also generally commercially acceptable; diffused light affects plant quality by providing a lower, more even temperature at plant level, thereby reducing the potential for 'hot spots' of light on foliage, and the scattered light reaches deeper into the crop increasing light interception by lower leaves. However, contrary to this, the *Salvia* Vista was affected by scorch in all plots under the Lumisol treatment, but not the Luminance; none of the other varieties were similarly affected. As there was no replication of treatments (only one tunnel for each cover type) it is not possible to determine to confirm the statistical significance of this.

SunSmart Blue can delay flowering and hold plants to meet marketing schedules. However in this trial, the Luminance (38% blue:62% red) treatment limited growth more successfully for a number of species including French marigold Durango, Geranium Horizon and *Petunia* Frenzy. There were slight differences in the light spectra and transmission afforded by the two SunSmart Blue tunnels due to slight sun damage to the older tunnel cover, but it is not considered that these differences were great enough to contribute to differences in plant performance recorded. Within this trial, generally, flowering was delayed, plant quality was higher and growth greater under the new SunSmart Blue film compared with the old SunSmart Blue film suggesting that growers will need to monitor the performance of these tunnel covers over time and replace them should any deterioration affect plant quality or scheduling.

UVA light transmission was reduced more under the SunSmart Blue tunnels than the Lumisol, Luminance and glass treatments. As UVA light is known to contribute to a reduction in stem elongation for many species, this suggests that any height reduction afforded by the SunSmart Blue tunnels in this trial may be due to the cooler environment, lower overall light transmission and the proportion of blue and red light, rather than UVA light.

It should be noted that as there was no replication of treatments (i.e. only one tunnel for each treatment), the statistical significance of these results cannot be confirmed.

This trial was a demonstration of the effects of spectral filters on growth and quality of a limited range of bedding plant species. It is clear from these results that different plant species respond differently to the changes to the environment afforded by the spectral filters and growers need to be aware of these effects when planning their use within a production programme.

SunSmart Blue tunnel covers are already used by bedding plant and HNS to hold plants back for marketing. The plants produced under the light diffusing films – particularly the Luminance - were of good quality, but were also more compact than those produced under other treatments, suggesting they could help to reduce plant growth regulator use. An additional benefit is that they not only provide a more even temperature throughout the crop, but also provide for a more comfortable working environment during warmer months.

Further trials using different plant species/varieties would help to build the knowledge base, and help to inform grower decisions on the use of spectral filters on their own holdings, and their effect plant growth and development.

Knowledge and Technology Transfer

- Blog: https://ahdbbppcblog.wordpress.com/
- Open days - 13 May and 23 June 2015
- AHDB Grower articles:

  England, J., Whiteside, C. (2015) HDC News Issue 210, pg. 28 - 30

  England, J., Whiteside, C. (2015) AHDB Grower Issue 219, pg. 15 - 18
- Presentations at GroSouth (November 2014 and November 2015) and the BPOA Technical Seminar (January 2015 and January 2016)

Acknowledgements

Our thanks to:

- Will Lamb and Jack Olds and the team at Baginton Nurseries for their work and commitment to the project.
- Roundstone Nurseries, Syngenta and Volmary / Delamore Young Plants for the provision of plant material.
- Rebecca Botham (ADAS) and the wider ADAS team.
- Dr Phillip Davis (STC) for his assistance with measuring and interpreting the light spectrum data.

References

Brough, W. (2003). Bedding plants: the use of low temperature storage as a scheduling aid. Horticultural Development Company Annual report for project PC 196

Crane, R., Christopher, H., Vaughan, R. (2013) Farm business survey (2011/12). Horticulture production in England. Rural Business Research at Reading.

Davis, P. (2015). Lighting: The principles. Technical Guide. AHDB Horticulture report for project CP085.

Fisher, P. Runkle, E. Blanchard, M., Erwin, J. (2011). FlowersOnTime: Temperature Effect on Days to Flower Version 1.2 June 2011. Floriculture Research Alliance (www.floriculturealliance.org). Available at: www.flor.hrt.msu.edu/annuals.

Huey, M. (2006) Horticultural crops: Demonstration of the potential benefits of modified plastic crop covers. HDC report for project PO 019.

Pearson, S., Parker, A., Adams, S. R., Hadley, P., May, D. R. (1995). The effects of temperature on the flower size of pansy (*Viola* x *wittrockiana* Gams.). *Journal of Horticultural Science* 70 (2) 183-190.

Pearson, S., Hadley, P., May, D.R., Parker, A., and Adams, S. R. (1993). The effects of temperature on bedding plants. HDC report for project PC 74.

Pearson, S. (1996). Bedding plants: effects of photo-thermal environments on growth, development and flowering. HDC report for project PC 74a.

Pearson, S. (1996). Optimising returns in bedding plant production. HDC report for project PC 74c.

Pearson, S. (2000) Bedding plants: the use of spectral filters to regulate plant growth. HDC report for project PC 150.

Warner R., J. Erwin, M. McDonough and N. Mattson. (2002). The Pros and Cons of Growing Plants Cooler. OFA Bulletin. No. 865. January 2002. pp 5 - 10.

Appendix 1: Seed vs cutting varieties of *Begonia boliviensis* and *Calibrachoa*

A) Photographs of all varieties, from both pots and packs, from week 11 and week 13 transplant, taken on 13 May 2015


Week 11


Week 13


Week 11


Week 13

Pots

Packs

Begonia boliviensis Bossa Nova (seed)


Week 11

N/A

Week 13


Week 11

N/A

Week 13

Pots

Packs

Begonia boliviensis La Paz (seed)*


Week 11


Week 13


Week 11


Week 13

Pots

Packs

Begonia boliviensis Million Kisses Amour (vegetative)


Week 11


Week 13


Week 11


Week 13

Pots

Packs

Begonia boliviensis Santa Cruz Sunset (seed)

N/A

N/A

Week 11 | Week 13 | Week 11 | Week 13

Pots | Packs

Calibrachoa Aloha Kona (vegetative)**

Week 11 | Week 13 | Week 11 | Week 13

Pots | Packs

Calibrachoa Cabaret (vegetative)

N/A		**N/A**	
Week 11	Week 13	Week 11	Week 13

Pots Packs

Calibrachoa Callie (vegetative)***

Week 11 Week 13 Week 11 Week 13

Pots Packs

Calibrachoa Crave (seed)

Week 11

Week 13

Week 11

Week 13

Pots | Packs

Calibrachoa Kabloom (seed)

* *Begonia boliviensis* La Paz (seed) week 11 only ** *Calibrachoa* Aloha Kona (vegetative) week 11 only *** *Calibrachoa* Callie (vegetative) week 13 only

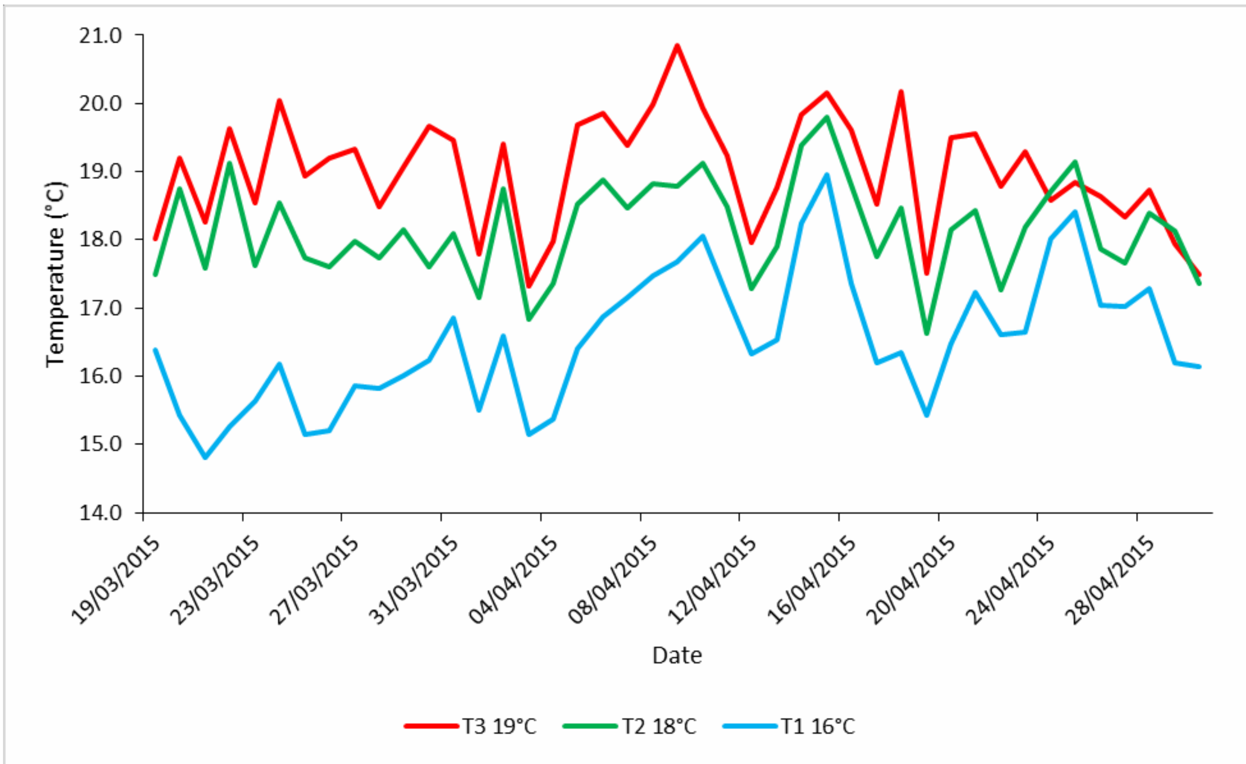
C) Visitor comments from open day on 13 May 2015 (Comments from four out of eleven visitors)

Variety		Seed / vegetative	Potting week	Score 1 - 9	Comments
Begonia boliviensis	Bossa Nova	Seed	11	Max = 9 Min = 6	Better plants, and better in 10.5 cm pot rather than 6-pack. Similar to 'Starshine' series. More flowers and more compact.
			13	Max = 9 Min = 5	Leaves seem a bit pale. Some soft growth and stretch.
Begonia boliviensis	La Paz	Seed	11	Max = 8 Min = 5	Looks too upright and a bit stretched. Not enough flower yet. Some soft growth.
Begonia boliviensis	Million Kisses Amour	Vegetative	11	Max = 9 Min = 7	Good foliage and flower colour. Soft growth.
			13	Max = 9 Min = 7	No comment
Begonia boliviensis	Santa Cruz	Seed	11	Max = 7 Min = 4	Poor growth habit for hanging baskets. Long internodes are unsightly. Some stretch evident. Poor basket cover.
			13	Max = 7 Min = 4	Not dense enough. Poor flowering.
Calibrachoa	Aloha Kona	Vegetative	11	Max = 9 Min = 6	Compact, lots of flowers. Compact habit and good flowering. Compact with nice flowering.
Calibrachoa	Callie	Vegetative	13	Max = 6 Min = 4	Not enough flowers. Stretched and soft growth. Looks stretched, poor habit, not much flower.
Calibrachoa	Cabaret	Vegetative	11	Max = 9 Min = 6	Good. More advanced but some over-flowering. More compact and lots of flowers, looks less forced. Better from 9 cm pot

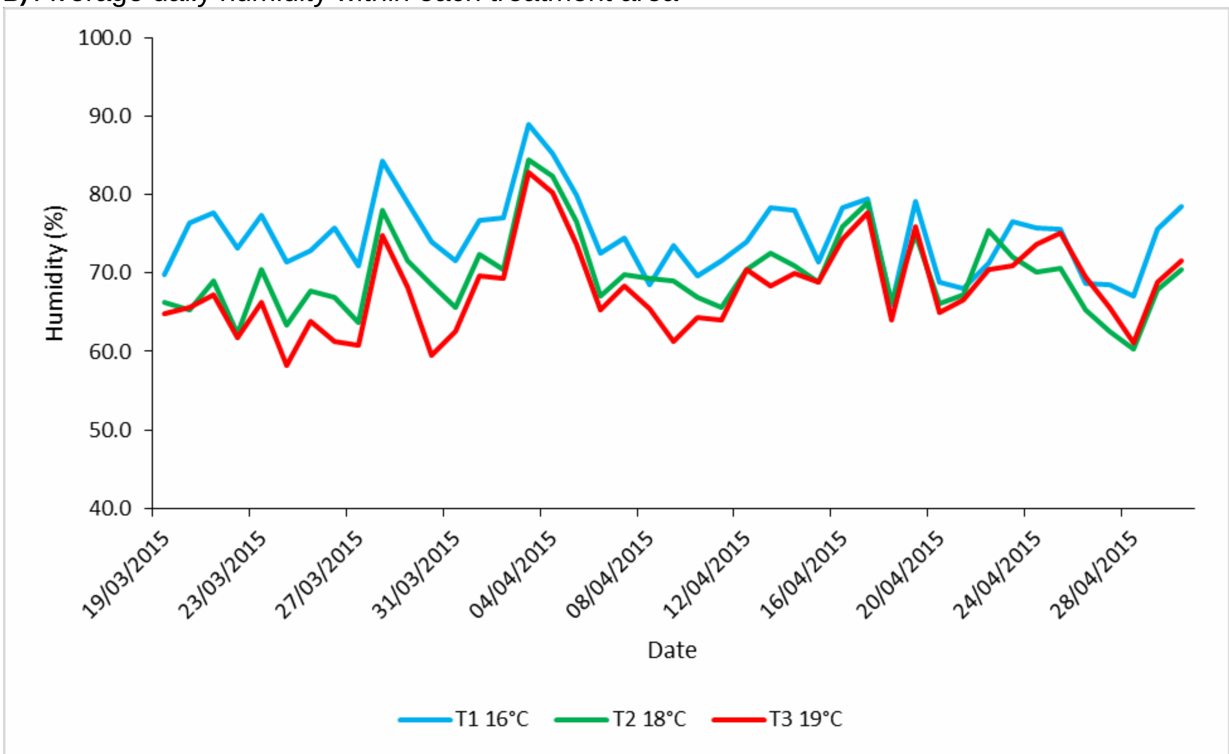
			13	Max = 9 Min = 6	Looks a bit stretched.
Calibrachoa	Crave	Seed	11	Max = 8 Min = 5	A little lax. More advanced flowering stage. Better flowering but big plants look messy.
			13	Max = 8 Min = 4	Big plants look messy.
Calibrachoa	Kabloom	Seed	11	Max = 9 Min = 6	Compact and lots of flowers. More advanced flowering, good basket habit. More compact, denser basket. More flowers, better from 6-pack.
			13	Max = 9 Min = 5	No comment

Appendix 2: Temperature effect on days to flowering

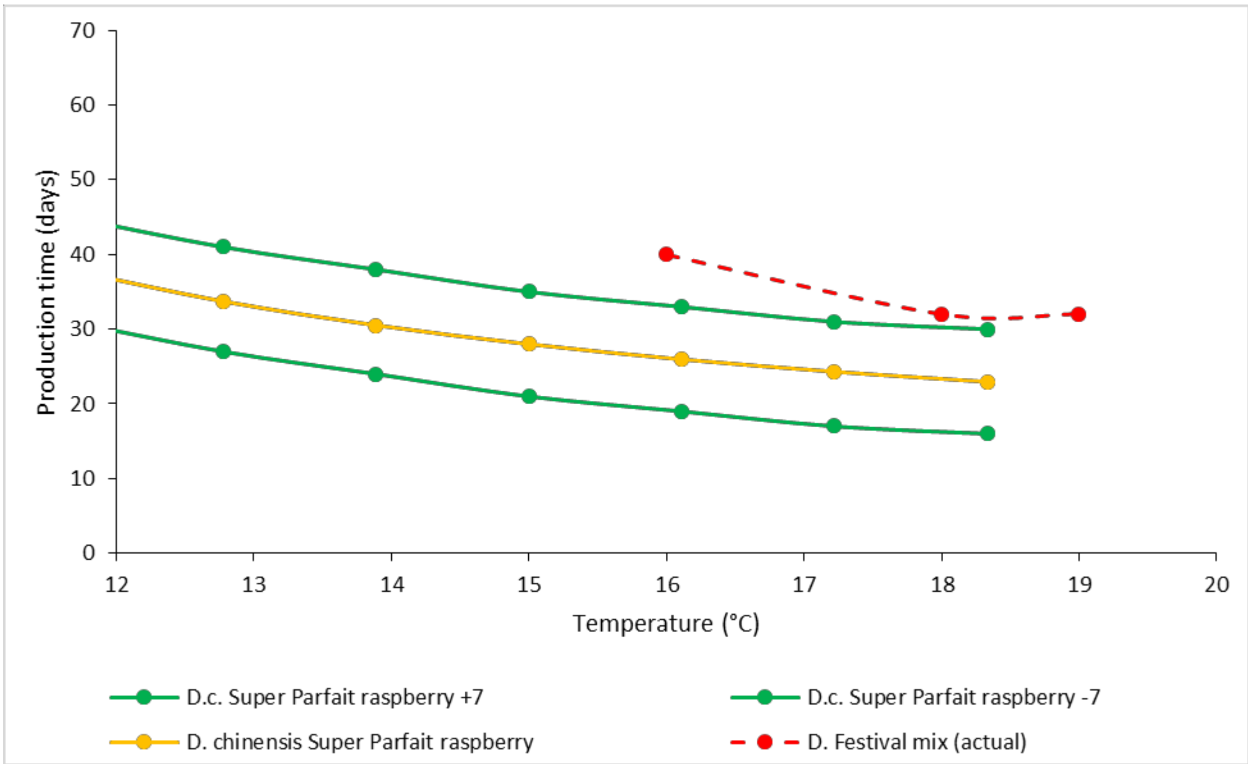
A) Average daily temperatures within each treatment area



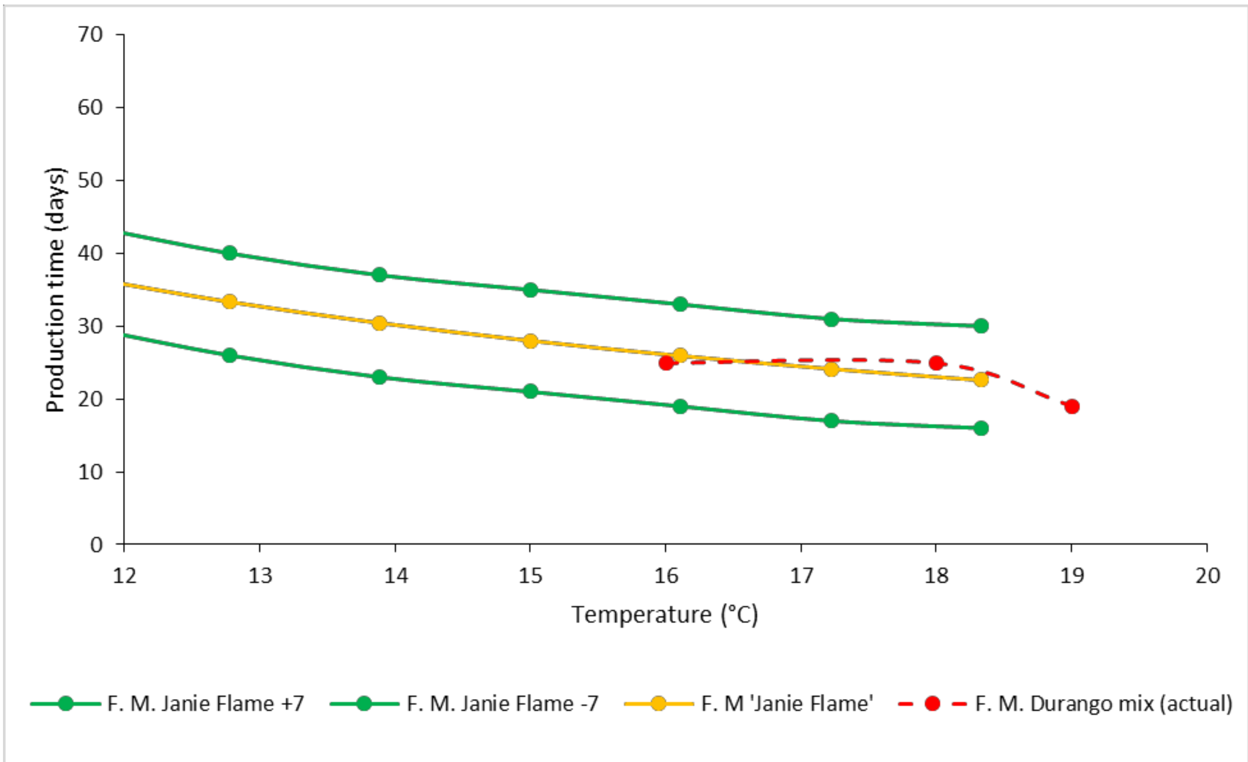
B) Average daily humidity within each treatment area



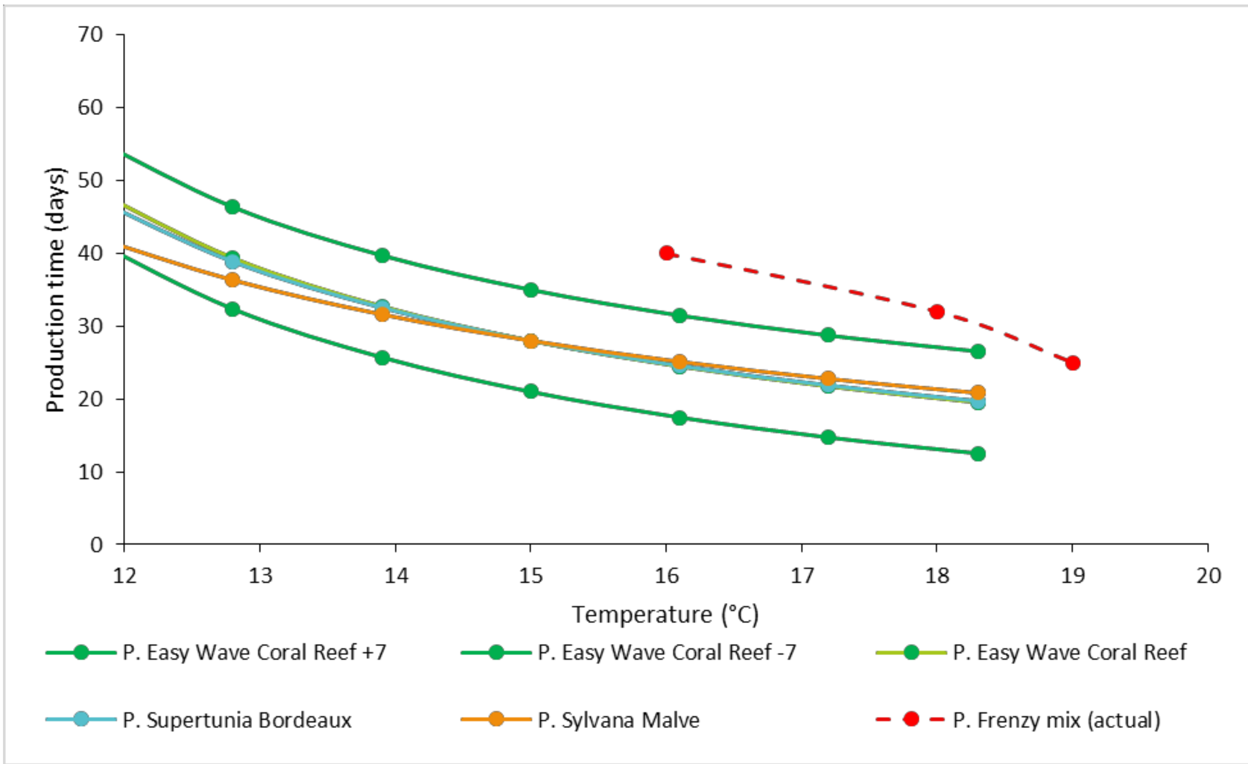
C) Production time – FlowersOnTime prediction vs actual – Dianthus



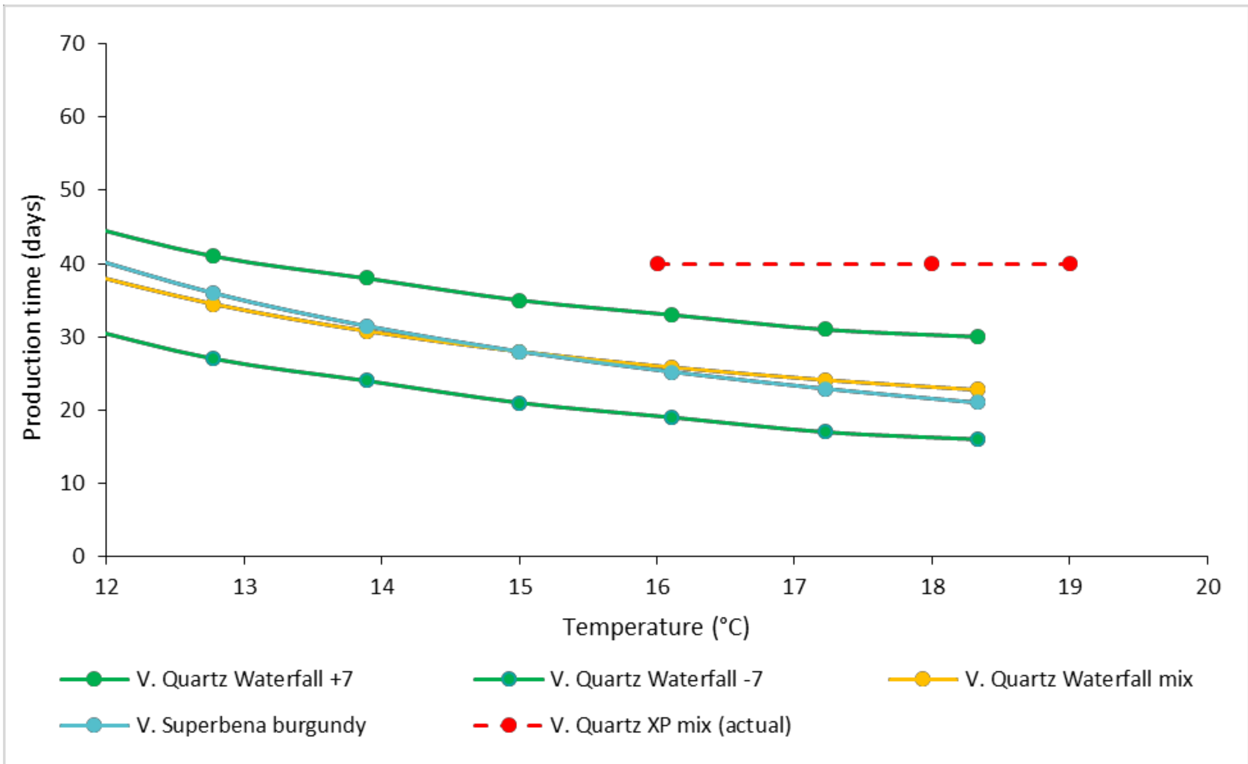
D) Production time – FlowersOnTime prediction vs actual – French marigold



E) Production time – FlowersOnTime prediction vs actual – Petunia

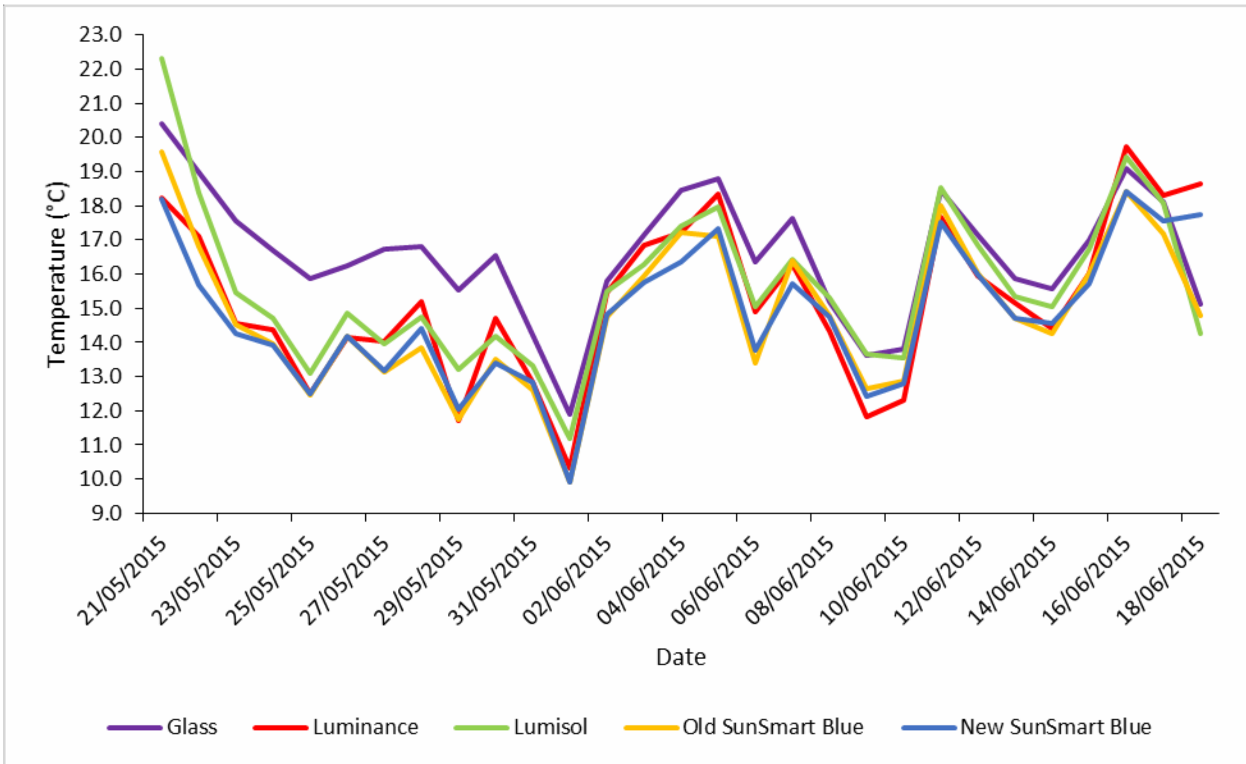


F) Production time – FlowersOnTime prediction vs actual – Verbena

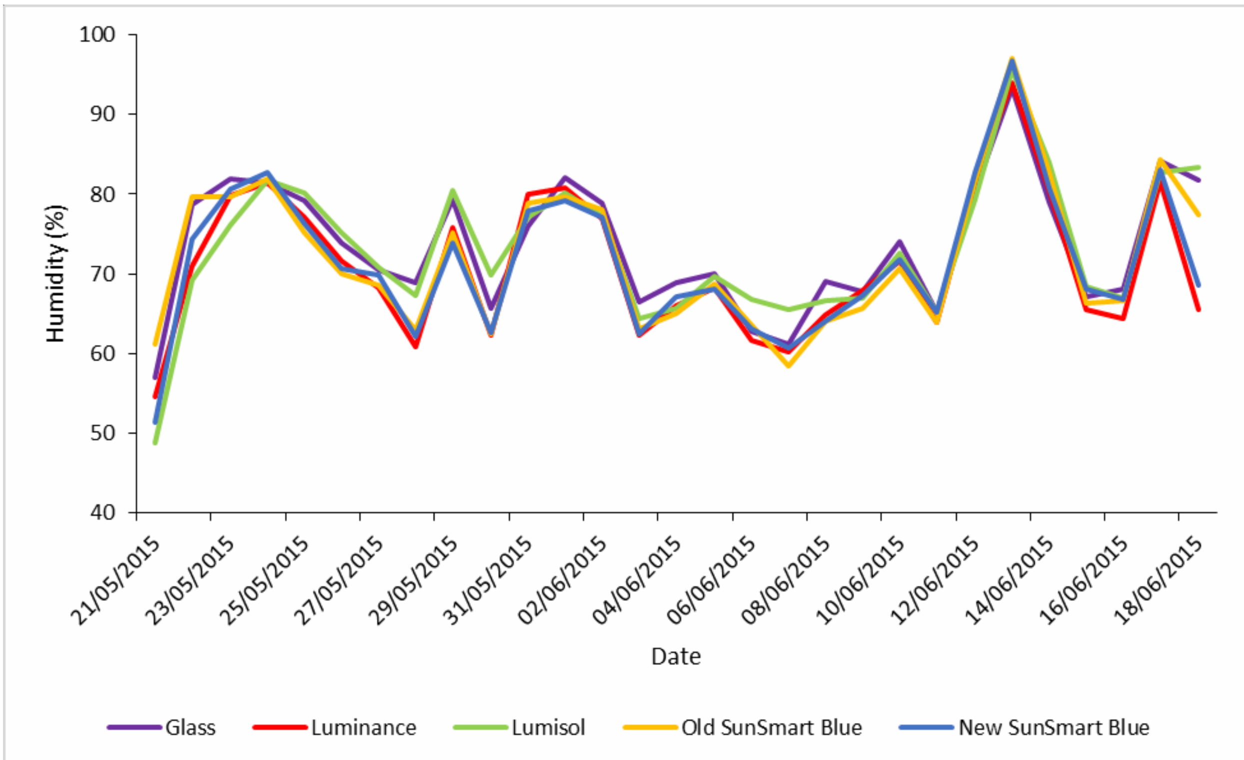


Appendix 3: Demonstration of spectral filters (film)

A) Average daily temperatures within each treatment area



B) Average daily humidity in each treatment area



C) Comparison of treatments – *Ageratum* 'Champion Blue'

Glass Lumisol Luminance Old SunSmart Blue New SunSmart Blue

D) Comparison of treatments – *Antirrhinum* 'Liberty' mix

Glass Lumisol Luminance Old SunSmart Blue New SunSmart Blue

E) Comparison of treatments – *Dianthus* ‘Festival’ mix

Glass | Lumisol | Luminance | Old SunSmart Blue | New SunSmart Blue

F) Comparison of treatments – French marigold ‘Durango’ mix

Glass | Lumisol | Luminance | Old SunSmart Blue | New SunSmart Blue

G) Comparison of treatments – *Geranium* ‘Horizon’ mix

Glass Lumisol Luminance Old SunSmart Blue New SunSmart Blue

H) Comparison of treatments – *Lobelia* ‘Regatta’ mix

Glass Lumisol Luminance Old SunSmart Blue New SunSmart Blue

I) Comparison of treatments – *Pansy* ‘Matrix’ spring select mix

Glass | Lumisol | Luminance | Old SunSmart Blue | New SunSmart Blue

J) Comparison of treatments – *Petunia* ‘Frenzy’ mix

Glass | Lumisol | Luminance | Old SunSmart Blue | New SunSmart Blue

K) Comparison of treatments – *Salvia* ‘Vista’ red

Glass | Lumisol | Luminance | Old SunSmart Blue | New SunSmart Blue

L) Comparison of treatments – *Viola* ‘Sorbet XP’ spring select mix

Glass | Lumisol | Luminance | Old SunSmart Blue | New SunSmart Blue

