FINAL REPORT

To:
Horticultural Development Company
Bradbourne House
Tithe Barn
East Malling
Kent, ME19 6DZ

HDC Project PC 224

IMPROVED SCHEDULING OF PRIMROSE

Steve Adams

Warwick HRI,

Wellesbourne, Warwick, CV35 9EF

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Commercial - In Confidence

Project title: Improved scheduling of primrose

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Project leader: Dr Steve Adams

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Key workers: Warwick HRI:

Dr Steve Adams – Project leader
Dr Veronica Valdes - Experimental co-ordinator
Angela Hambidge & Jayne Akehurst – Apical dissections

STC:
Cathryn Lambourne - Experimental co-ordinator
Deborah Liddell & Iwona Burdon – Data collection

ADAS:
Wayne Brough - Consultancy

Location: Warwick HRI, Wellesbourne, Warwick, CV35 9EF

Project co-ordinator: Alan Davis - Appletree Lodge, Shepherds Lane, Chard, Somerset, TA20 1QU

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Signed on behalf of: Warwick HRI

Signature:...Simon Bright ..... Date: *24 July 2008*

Name: Professor Simon Bright
Director and Head of Department

CONTENTS

Headline

A model has been developed which can predict the time of flower initiation and flower opening in primrose to a reasonable degree of accuracy. Low light levels delay flower initiation and development, and increase blindness. The optimum average temperature appears to be around 15°C for flower initiation, although once initiated higher temperatures hasten flower opening.

Background and expected deliverables

Primrose (*Primula vulgaris* Huds. or *P. acaulis* L.) is a very important seed-raised bedding plant. Over 70 million primrose and polyanthus plants are grown annually in the UK (ADAS estimate) and the crop is estimated to have a wholesale value of over £21M. Growers estimate that wastage averages around 10%, although this can vary from 5 to 35% depending on the year. This is, in part, due to problems associated with crop scheduling; there is often a glut of plants in February.

Whilst growers currently use a wide range of varieties with different flowering periods (and occasionally cold storage) to improve crop scheduling, it was felt that production systems could be improved through a better understanding of how the environment regulates flowering in primrose.

Summary of the project and main conclusions

Cultivar and flower colour

Generally speaking the cultivars Primera (Quantum), Danova and Finish (all yellow) initiated within a couple of weeks of one another when sown at the same time, Finish tending to be slightly later. However, there was greater differences in the rates of flower development and consequently Primera (Quantum) tended to flower first, followed by Danova and then Finish. Different flower colours were

included in the trials at STC, but it was impossible to generalise about flower colour as the series differed and the results were not consistent over the two years.

Plug size

Three plug trays were used at Warwick HRI, '104', '216' and '336' and in all cases plants usually initiated after potting on. When plants were potted up as soon as they were of an appropriate size, there was no difference between trays with regards to the time of subsequent initiation or flowering (expressed as days from sowing), although clearly the time of transplanting varied.

Cold storage

When initiated plants grown in large modules were placed into cold storage, subsequent flowering was delayed by around 4 days for each week of cold storage (Figure 1). Interestingly, cold stored plants tended to be much smaller when they flowered. However, it proved very difficult to reliably initiate plants in plug trays that would be small enough to be viable commercially. Cold storage can nevertheless be used to hold back plugs, although this will not avoid the problem of blindness seen in some late sown crops.

Figure 1. *Photograph showing the effects of cold storage on the size and flowering time of cultivar Finish*

At STC plants were successfully held in cold store for up to 12 weeks in 2006/7. On the whole the plants that were brought out of cold store after 4 or 8 weeks went on to flower at a very similar time to those that had been sown a month or two later. However, the plants that were cold stored for 12 weeks were later to flower when compared with other material potted at the same time. This might suggest that storing plants for too long can be detrimental, although this could equally well be due to problems that occurred in this experiment with plant nutrition.

Environmental triggers for flowering

In the first experiment at Warwick HRI plants were grown on photoperiod trolleys where they were exposed to daylengths of 8, 11, 14 and 17 hours. There was an increase in the incidence of polyanthus stem in Primera (Quantum) when given a 17h day, however, daylength did not affect the time of flower initiation or flower opening. Natural daylengths were used in all of the subsequent experiments.

Another experiment compared no shading, light shading (light transmission of 72%), and heavy shading (light transmission of 33%) for crops sown in week 32. Heavy shading delayed flower opening by approximately 20 days. This delay was greater than the delay in flower initiation suggesting that shading also prolonged flower development.

A subsequent experiment at Warwick HRI involved growing plants in glasshouse compartments under three temperature regimes; 'Warm' (heating 18°C, venting 20°C), 'Ambient' (heating 3°C, venting 5°C) and 'Summer cooled' (heating 3°C, venting 5°C, air conditioning above 18°C). In the ambient and warm compartments plants were grown with or without heavy shading (transmission 32%). Summer cooling hastened initiation of plants sown in week 25, while warm temperatures delayed initiation of plants sown in week 34 (Figure 2). While higher temperatures

delayed flower initiation, once initiation had taken place flowers developed more rapidly in the warm compartment.

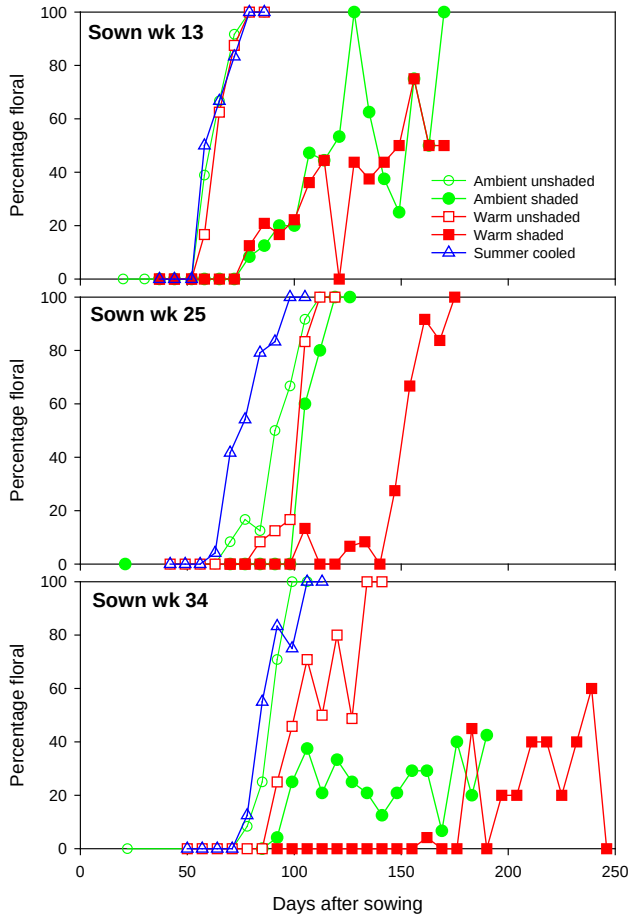


***Figure 2**. The effects temperature and shading (average of all three cultivars) on the time of flower initiation*

Shading greatly delayed flower initiation and increased variability, particularly when in combination with high temperatures. Initiation sometimes ceased when light levels fell and then plants resumed initiation when conditions improved. Plants that received on average less than 2mol/m^2/d of light from the start of the experiment did not initiate flowers before the end of the experiment. For all of the cultivars shading also delayed flower bud development. Many of the plants grown under high temperatures with shading never flowered, either due to blindness and/or plant death due to low assimilate levels.

Two subsequent experiments at STC compared ambient light conditions with supplementary lighting (~50 µmol/m^2/s, equivalent to around 4,000 lux, from 08:00 to 16:00 GMT) and shading (nominally 70% shade). In 2006/7 plants where sown and raised at STC while in 2007/8 commercially grown plugs were used. Although in both cases the treatments commenced at potting up (unlike the Warwick HRI experiments where treatments started at seedling emergence).

In 2006/7 the ambient and lit plants initiated at a similar time, and these treatments reached the stage where 100% of the plants were floral within a week or so of each other. The one exception was the July and August sowings of Finish, here the lit plants reached the point were they were all floral a couple of weeks before those grown under ambient conditions. This would tend to suggest that at this time of year (October to mid November) ambient light levels were limiting. The first couple of sowing dates actually showed a very slight delay in flowering due to lighting, while the later sowings showed a slight hastening as a result of lighting. Shading delayed flower initiation particularly for the later sowing dates. In some cases the percentage of floral plants never reached 100% indicating blindness. The shaded plants flowered much later than the ambient or lit plants (Figure 3). The delay was an average 40 days, although this is an underestimate as a number of plants from this treatment were blind and had not flowered by the end of the experiment.

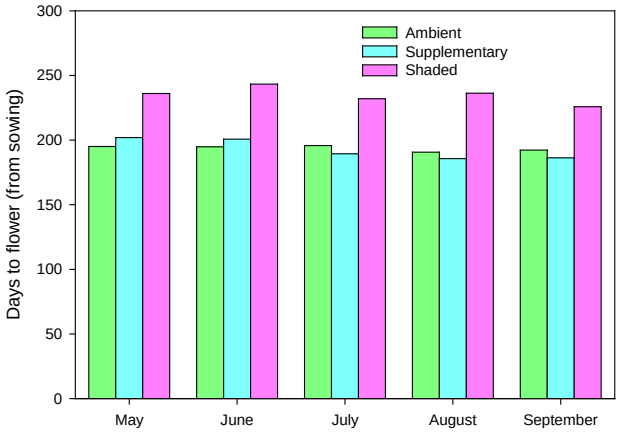


***Figure 3**. The effect of lighting treatment and sowing date on the time to flowering at STC in 2006/7, calculated as the number of days from sowing, averaged across all cultivars and colours*

However, in 2007/8 shading only appeared to cause a delay compared to the lit crop for Finish which was potted in weeks 36 and 39. The plants grown under ambient conditions tended to flower first, although this may have been due to fact that this glasshouse compartment was an average 4°C warmer that the compartment containing the lit and shaded treatments from the end of September onwards.

Modelling flower initiation and flowering time

All of the initiation dates for the trials at Warwick HRI were combined and modelled. The optimum temperatures from the start of the experiment to flower initiation appeared to be 15 - 16°C for all three cultivars; flower initiation was predicted to be delayed by higher or lower temperatures. Low light levels were predicted to cause large delays in flowering time, especially below 2 mol/m^2/d (around 1 MJ/m^2/d total solar), although the critical threshold changed with temperature. Similarly the durations from initiation to flower opening were combined and modelled; high temperatures are predicted to hasten flower development as are high light levels, although the increases plateau.

The models were tested against data collected from STC in 2007/8 and from crops grown on two commercial nurseries (Avoncross and Coletta) in 2007/8 from commercially raised plugs sourced from different suppliers. While there were differences between flower colour and suppliers the differences were not consistent and so the same models (developed for yellows) were used for all crops. As the plugs were bought in the models could not be run from seedling emergence, instead it was assumed that the plugs were 20% of the way to flower initiation at the time of potting up. Despite the assumptions made the models were reasonably accurate at predicting the initiation and flower dates of the ambient crops at STC. However, lighting was predicted to hasten flowering slightly and shading was expected to result in considerable delays. This was not the case at STC in 2007/8, although this is what was observed in the previous trials. The model was tested in the same way using data from the commercial crops. The time at which 50% flowering was observed was compared with the predicted mean flowering time (Figure 4). The predictions for crops at Avoncross were accurate within two weeks for all crops except the week 36 Finish which flowered around a month earlier than predicted by the model. Similarly the flowering times of first crops at Coletta were predicted to within a week, while greater errors occurred with the crops that were delivered in week 36. This suggests that slight recalibration may be needed if the models are used from potting up for crops that over winter.

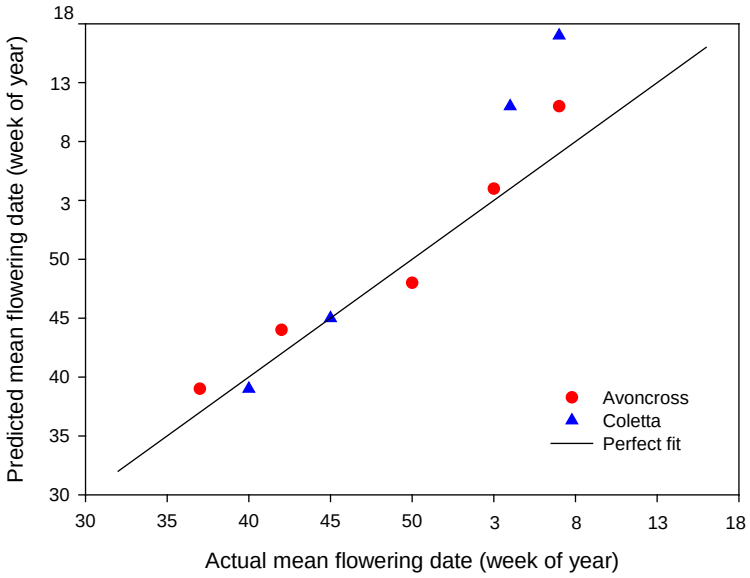


***Figure 4**. Comparison of the estimated 50% flowering date with the mean flowering date predicted using the model for both commercial sites*

Financial benefits

The primrose crop is estimated to have a wholesale value of over £21M and growers estimate that wastage averages around 10%. If the information derived as part of this project reduced wastage to 9%, that would equate to an annual saving of £210K per annum.

While supplementary lighting has a high cost for relatively little benefit, other techniques, such as optimising sowing dates and avoiding unnecessary shading, can carried out at low cost and would have a good payback.

Action points for growers

- To reduce blindness in autumn/winter, maximise the light transmission by cleaning the glass and avoiding unnecessary shading. This will be particularly important for late sowings.
- Supplementary lighting had relatively little impact on flower initiation or flowering time. Substantial benefits are only expected when the ambient light levels are very low (below around 2 mol/m^2/d or 1 MJ/m^2/d total solar).

- Plants usually initiate after they have been transplanted; to avoid delayed initiation do not hold plants in plug trays for a prolonged period.
- Unfortunately, it is not possible to assess whether flower initiation has occurred by simply looking at leaf numbers or plant size.
- Cold storage does not induce flowering, although can be used to hold plants prior to transplanting. Cold stored plants generally initiate and flower at a similar time to late sown crops transplanted at the same time.
- Try wherever possible to avoid high temperatures post-transplanting, particularly when light levels are low. The optimum average temperature for flower initiation is around 15°C.
- Warm temperatures after flower initiation can hasten flowering but may adversely affect quality.

SCIENCE SECTION

Introduction

Primrose (*Primula vulgaris* Huds. or *P. acaulis* L.) is a very important seed-raised bedding plant. Over 70 million primrose and polyanthus plants are grown annually in the UK (ADAS estimate) and the crop is estimated to have a wholesale value of over £21M. Growers estimate that wastage averages around 10%, although this can vary from 5 to 35% depending on the year. This is, in part, due to problems associated with crop scheduling; there is often a glut of plants in February. The weather also influences the pattern of sales and the plant quality.

Crops are typically sown from June to July and marketed over the autumn/winter months. Yet despite the importance of this crop there is a poor understanding of the environmental factors that trigger flower initiation or control the rate of flower development. When crops are sown late there is a tendency for increased blindness. Late crops also tend to suffer from an increased incidence of polyanthus status (polyanthus stem) where clusters of flowers are borne on stems rather than on a short pedicel attached directly to the crown of the plant.

Whilst growers currently use a wide range of varieties with different flowering periods (and occasionally cold storage) to improve crop scheduling, it is felt that production systems could be improved through a better understanding of how the environment regulates flowering in primrose.

The work carried out in years 1 and 2 at Warwick HRI showed that daylength had little effect on the time of flowering of primrose cultivars Quantum, Danova and Finish. Flowering was shown to be controlled by light level and temperature. Low

light levels delayed flower initiation and development, and increased blindness. The optimum temperature for flowering appeared to be around 15°C for flower initiation, although once initiated higher temperatures hastened flower opening. Mathematical models were developed which quantified these relationships. In year 3 a trial at STC confirmed that light levels were critical in determining the time of flower initiation. The work also confirmed that plants do not initiate in cold stores, they initiated after potting up at a similar time to those sown later and potted up at the same time. This report focuses on the fourth year's experiments at STC which set out to validate the model, and assess whether it could be used for commercial plugs without knowing their history. Crops were also grown at two commercial nurseries.

Materials and methods

Stockbridge Technology Centre (STC)

The main experiment was conducted at STC. The aim was to examine the variation in time of flower initiation and flower opening of plugs bought in from a range of commercial suppliers. Primera was obtained in weeks 28 and 32 (week 33 from Sakata), Danova was obtained in weeks 32 (week 33 from Sakata) and 36, and Finish in weeks 36 and 39. The plants were bought from commercial production with the exception of Bordon Hill Nurseries who kindly agreed to sown seed specifically for the project, hence these trays were not gapped up. A full list of plugs can be seen in Table 1.

Table 1. *Plant material sourced for using in the experiment at STC*

Series	Supplier	Tray size	Colour	Potting Weeks	
Primera	Young Plants	264	yellow, red, blue	28	32

	Pentland	230	yellow, red, blue	-	32
	Bordon Hill	240	yellow, red, blue	28	32
	Sakata	286	mix	28	33
Danova	Young Plants	264	yellow, red, blue	32	36
	Pentland	230	yellow, red, blue	32	36
	Bordon Hill	240	yellow, red, blue	32	36
	Sakata	286	mix	33	36
Finish	Bordon Hill	240	yellow, red, blue	36	39
	Florensis	288	yellow, red, blue	36	-

Plants were transplanted into 9cm pots filled with a Bulrush primrose growing medium. Plants were irrigated with water during the first week after transplanting, and were subsequently fed with Peter's Excel 18:10:18 at every irrigation (100 ppm N). Plants were then grown on in two 200m^2 glasshouse compartments, where the following treatments were applied (see appendix 1 for details of experimental layout):

- Supplementary lighting (~50 µmol/m^2/s, equivalent to around 4,000 lux, from 08:00 to 16:00 GMT)
- Ambient light
- Shaded (nominally 70% shade)

The glasshouse compartments were set to provide a minimum temperature of 3°C and venting at 5°C. Temperature and relative humidity data were obtained via the Priva computer, and light sensors (Quantum sensors) were positioned towards the centre of each of the three light treatments.

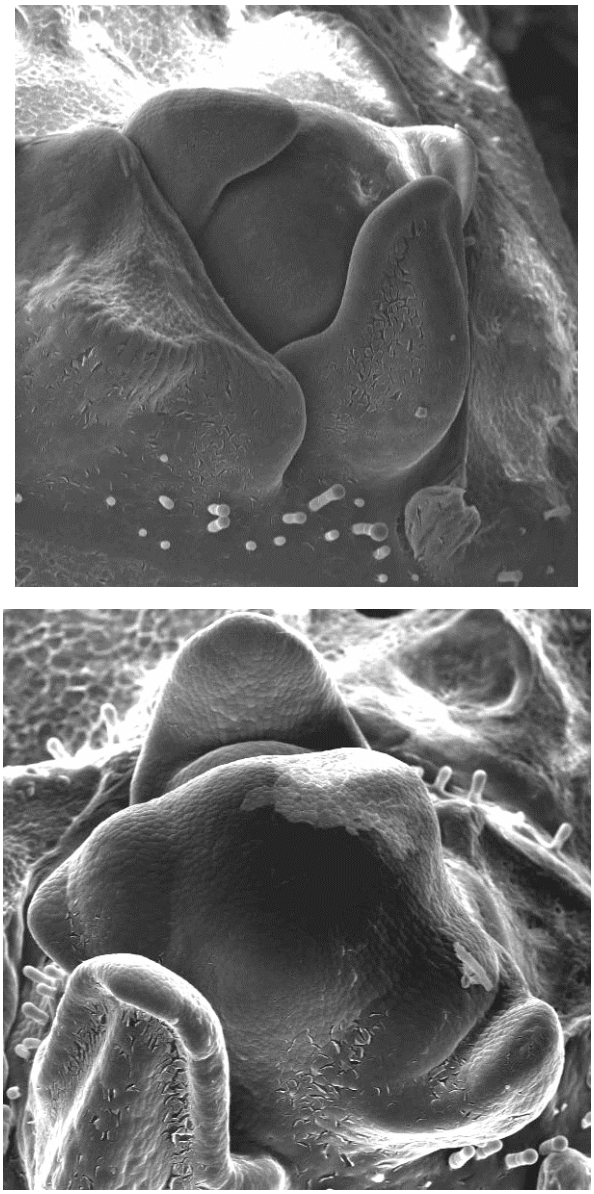


Figure 1. *Scanning electron microscope images of primrose terminal apices. The image on the left shows a vegetative apex with a typical domed shape and young leaf primordia. The right hand image is of an apex at an early stage of flower initiation. The apex is no longer domed and flower primordia are starting to differentiate in the leaf axils*

Plants were dissected using a binocular microscope at weekly intervals (~ 6 plants per treatment per week) to assess whether plants were vegetative or floral (Figure 1). Shoot fresh weights, the number of leaves greater than 1cm in length, and the

number of smaller leaf primordia were recorded. There were 4 blocks of 18 plants for each of the above treatment combinations. Most were dissected and 18 plants were grown on to flower. The date on which the first flower opened was recorded for each of these plants.

Commercial nurseries

A small subset of the plant material used at STC (see Table 2) was also grown on at two commercial nurseries (Avoncross Ornamentals, and Coletta and Tyson). Trays from the same batch of plants as used at STC were transported to each site and grown on alongside commercial crops. At Avoncross plants were grown in double 6 packs, while at Coletta and Tyson they were grown in 9 cm pots.

Table 2. *Plant material sourced for using in the experiment on commercial nurseries*

Series	Supplier	Tray	Colour	Potting weeks	
Primera	Young plants	264	yellow	28	32
Danova	Young plants	264	yellow	32	36
Finish	Florensis	288	yellow	36	-

Air temperatures and light levels were recorded using shielded thermisor sensors and quantum sensors connected to data loggers positioned next to the crops (Figure 2).

Figure 2. *Experimental plots sited on commercial nurseries*

Plants were dissected using a binocular microscope at weekly intervals (~ 12 plants per treatment per week) to assess whether plants were vegetative or floral (Figure 1). Plants from Avoncross were collected and dissected by staff at Warwick HRI, while the plants from Coletta's were dissected by staff at STC. Shoot fresh weights, the number of leaves greater than 1cm in length, and the number of smaller leaf primordia were also recorded.

Results

Stockbridge Technology Centre (STC)

Environmental conditions achieved

Initially the glasshouse compartment which contained the lit and shaded treatments was slightly warmer than the ambient compartment; this difference averaged 1.2°C up until the end of September. Thereafter the temperature in this compartment fell (averaging 8.5°C from October to the end of the experiment) while the ambient compartment maintained an average temperature of 12.7°C (Figure 3A).

Unfortunately this difference in temperature is confounded with the lighting treatments, and so care is needed when making treatment comparisons. Similarly there were differences in the measured RH when comparing the two compartments (Figure 3B).

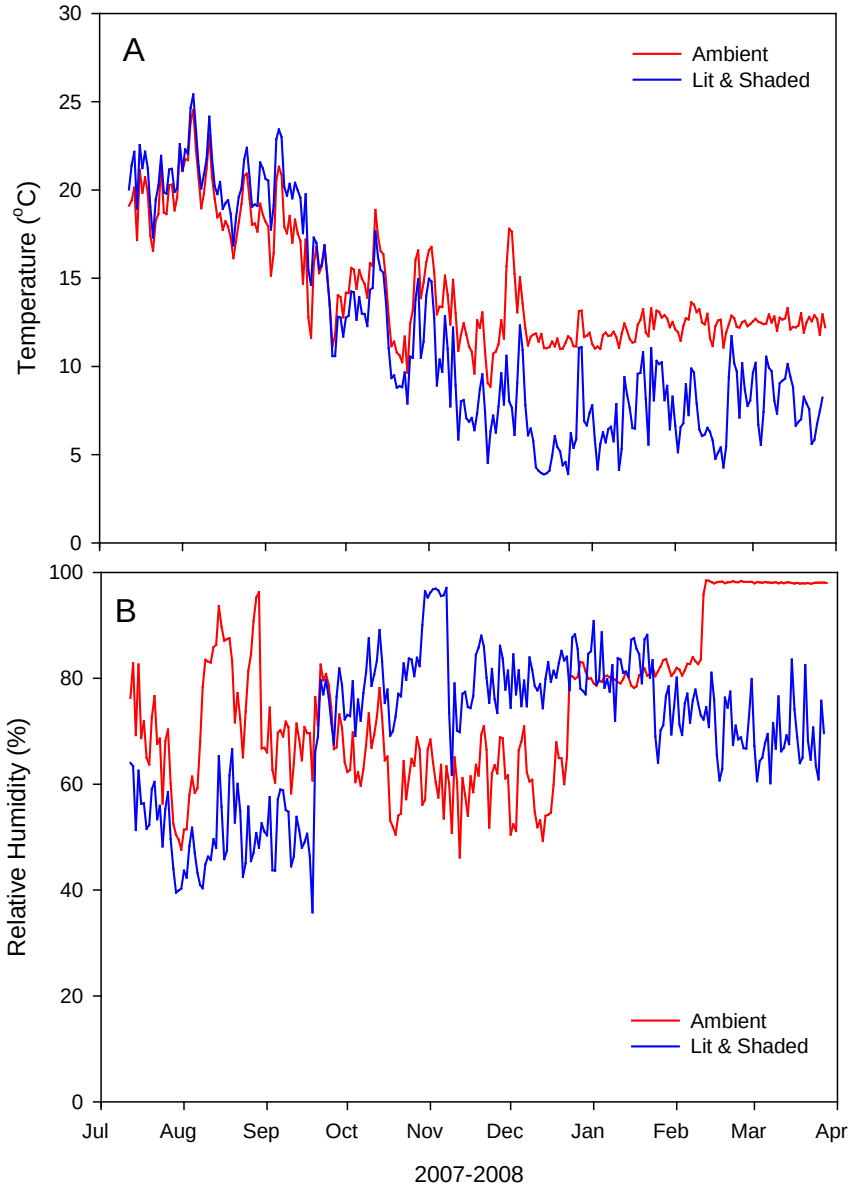


Figure 3. *Mean diurnal air temperatures and humidity recorded in the two experimental glasshouse compartments at STC. The lit and shaded treatments were imposed in one compartment and the ambient treatment was in a separate compartment*

The light levels in each of the three lighting treatments can be seen in Figure 4A. The shade material decreased the light by on average 76% (Figure 4B) which is slightly more than that seen in the previous year (72%) and the nominal properties of the shade material. The difference between the ambient and lit treatments (Figure 4C) was initially variable and more than could be explained due to the supplementary lighting (50 µmol/m^2/s for 8 h/d would give 1.4 mol/m^2/d). This was probably due to shading and positional effects within the glasshouse facility. However, over the winter months the difference between the two treatments was close to that expected.

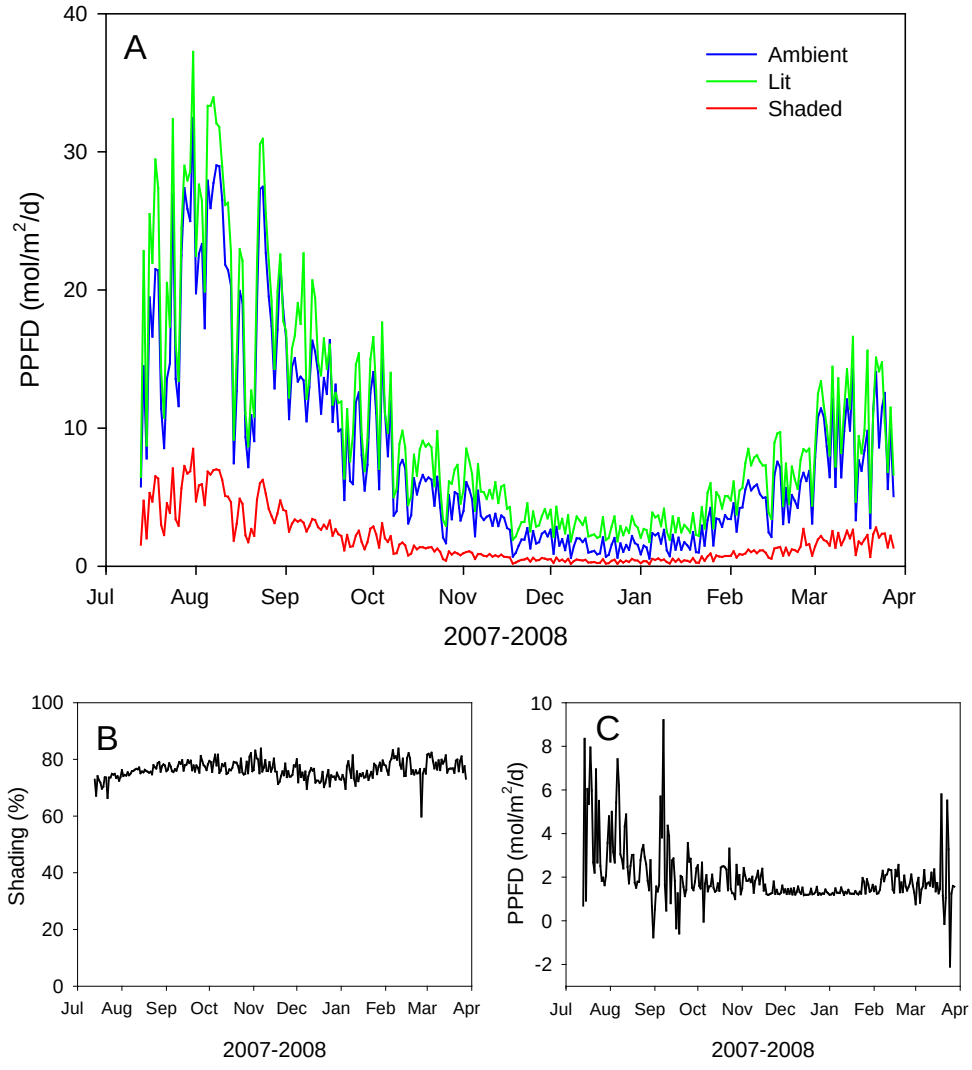


Figure 4. *Comparison of the light levels (photosynthetic photon flux density; PPFD) in the different lighting/shading treatments (A). The percentage shading is shown*

in B, and the additional light in the lit treatment, when compared with the ambient plot, is shown in C

Flower initiation

Effects of series and delivery week

There was a tendency for Primera to initiate quickly from potting up, followed by Danova and then Finish (Figure 5A). However, this may not have been entirely due to differences between the series. There was a seasonal effect, which may in part have accounted for these differences. For example, Primera delivered in week 28 initiated earlier (when expressed as days from potting) than the crop delivered in week 32.

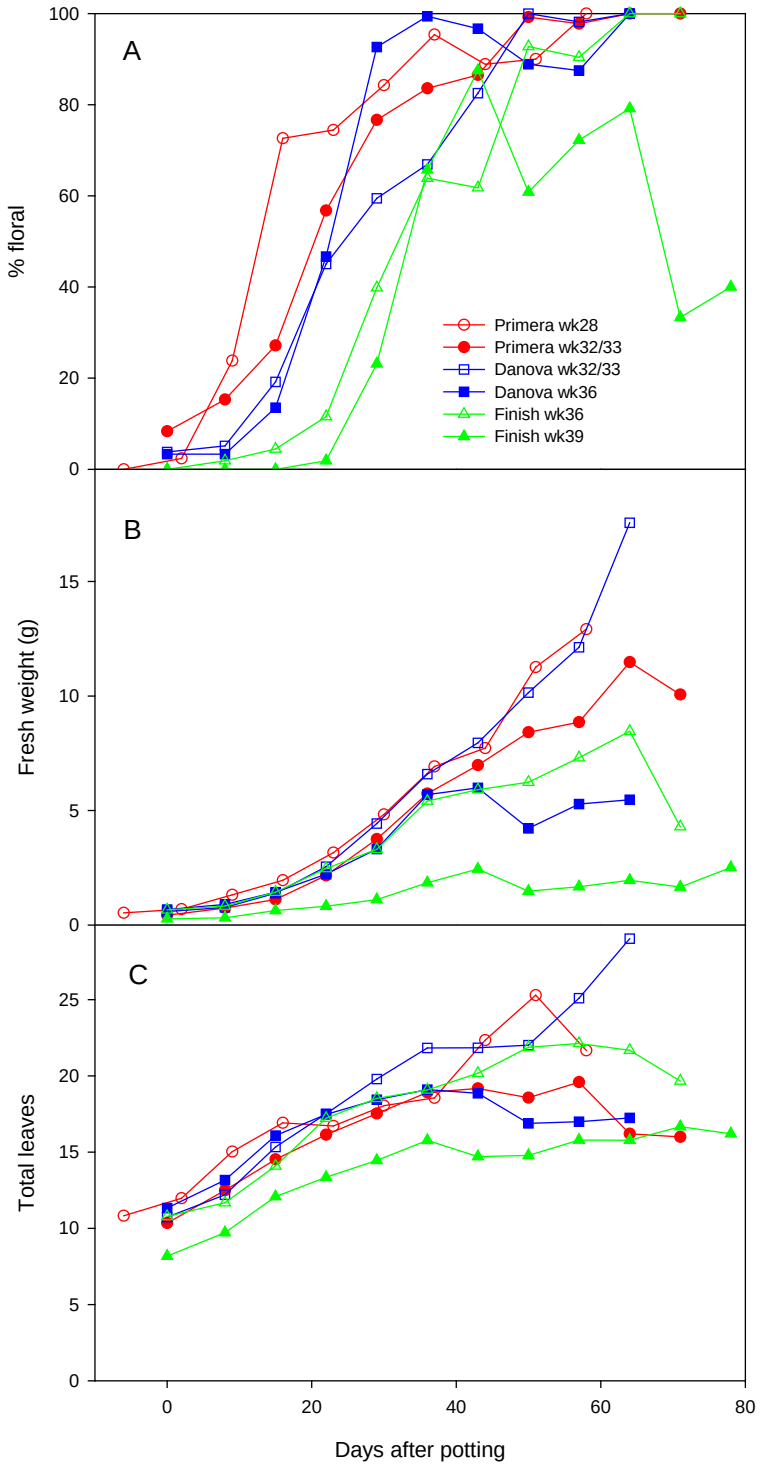


***Figure** 5. The effect of series and delivery week on A) flower initiation, B) shoot fresh weight, and C) the increase in leaf number*

There were also differences between series and delivery week in terms of shoot fresh weights and leaf numbers (Figures 5B and 5C). The most noticeable being Finish delivered in week 39 where weights and leaf numbers were reduced.

Effects of flower colour

The differences between the colours were not consistent across all of the series and potting weeks (Figure 6). The mixed trays showed greater variability from week to week with regards to the number of plants that were floral. While this might be due to additional genetic variability, it should be born in mind that there was only a single mixed tray for any given series/delivery week combination (giving 6 plants per dissection). Whereas there were more trays of single colours which means that each point on the graph represents the average of more plants (up to 18 plants).

The data would suggest that for Primera and Danova blue plants initiate slightly earlier than red or yellow, however, this appeared to be the case only in the earlier of the two delivery dates for both species. This inconsistency might be due to the fact that plugs were bought commercially and so not all of the colours will have been sown on the same day. Furthermore, these differences are not consistent over years; in the 2006 experiment at STC yellow Primera initiated before red or blue, and for Danova the reds initiated first.

Blue Finish initiated slightly later than the other colours, although again this may have been due to differences between trays on arrival. The trays of blue Finish were more variable with regards to germination and plant size was reduced (Figure 7).

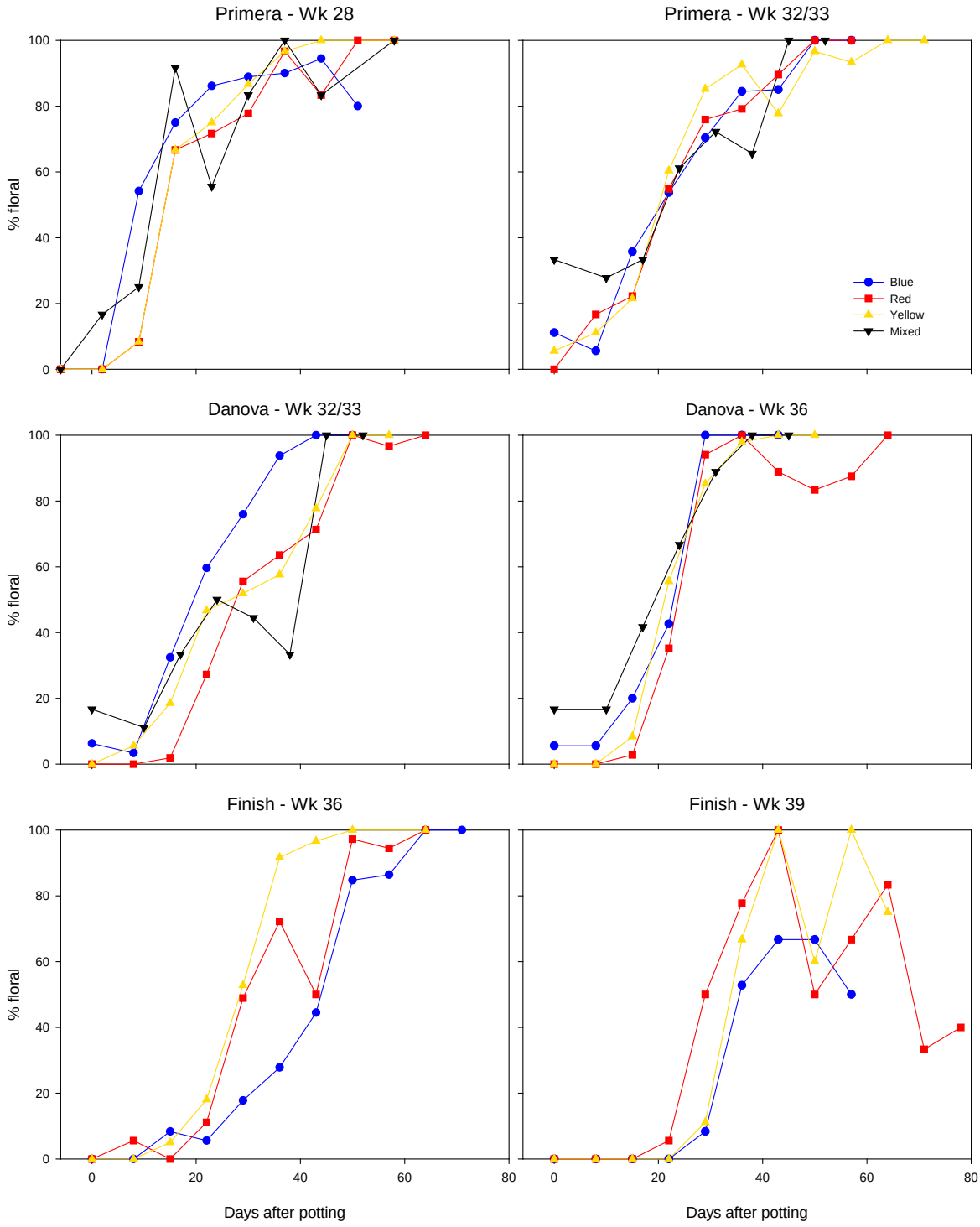


Figure 6. *The effects of flower colour on flower initiation. The data are averaged across suppliers and lighting treatments*

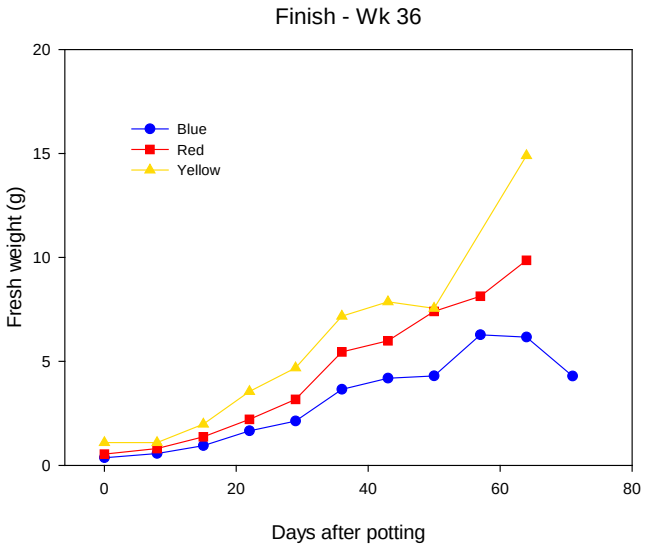


Figure 7. *The effect of flower colour on the increase in shoot fresh weight over time for Finish delivered in week 36. The data are the average across suppliers and lighting/shading treatments*

Effects of lighting/shading treatments

The effects of lighting and shading were surprisingly small in this trial (Figure 8) when compared with the findings from previous trials. The only time when shading gave a marked delay in the time of flower initiation was for Finish delivered in week 39. Considerable delays were seen as a result of shading in the initial trials at Warwick HRI. However, in the trials at Warwick HRI the plants were grown under shaded conditions from seedling emergence and so the treatments affected plug growth and probably the length of the juvenile phase of development when plants cannot be induced to flower. Nevertheless shading also had a marked effect in the 2006/7 trial at STC particularly for the crops sown in July and August; while the plants were raised at STC, the treatments were not imposed until the plants were potted up. Furthermore, in the 2006/7 trial, lighting hastened flower initiation of plants sown later and this was not observed in the current trial. Conversely, for some of the 2007/8 STC crops lighting appears to have slightly delayed initiation.

As indicated earlier the lighting treatments were spread across two glasshouse compartments which achieved different temperatures and so the effects of light and temperature were confounded. Nevertheless the differences between the shaded and lit treatments were also unexpected and these treatments were in the same compartments and so can be directly compared.

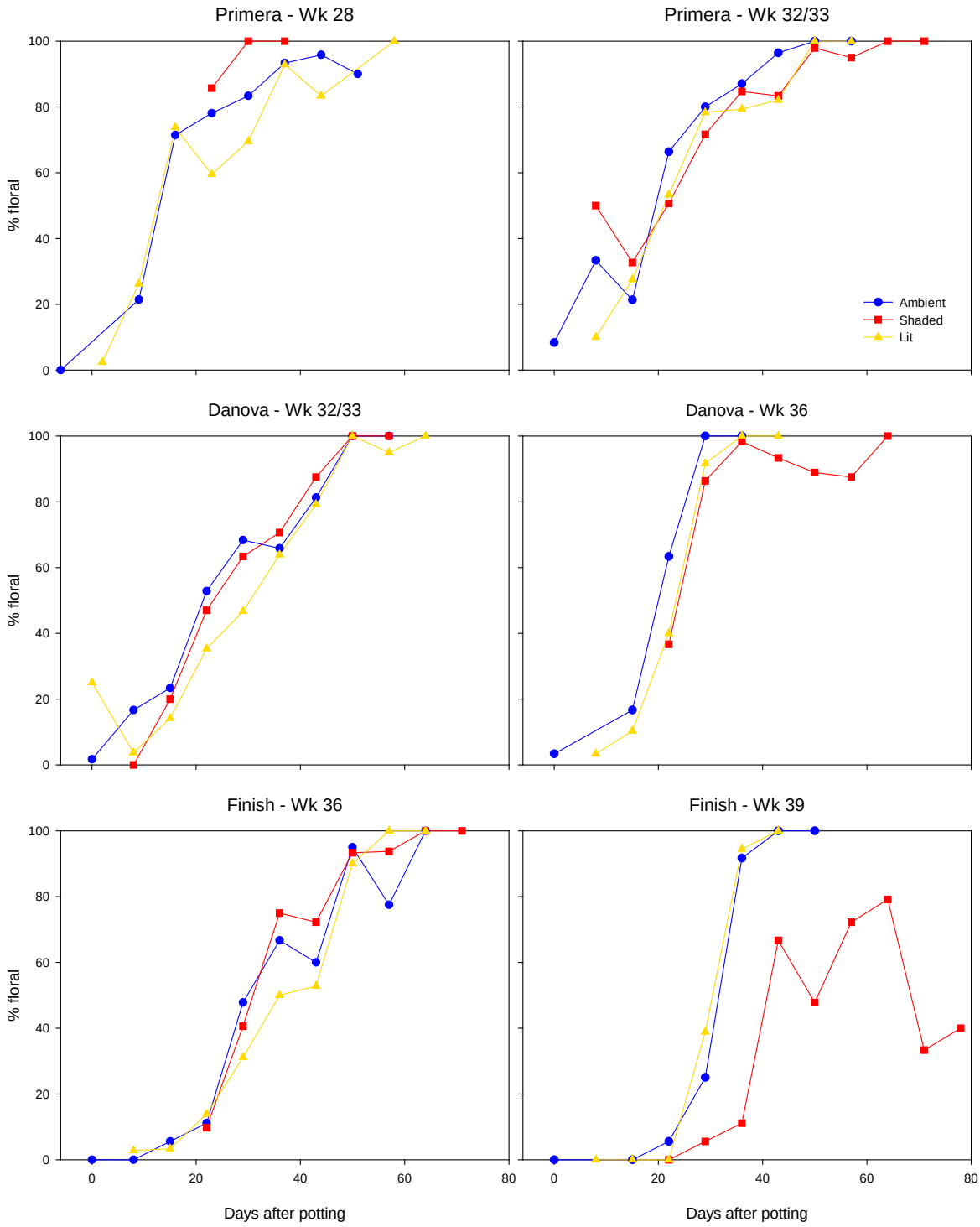


Figure 8. *The effects of lighting/shading treatments on flower initiation. The data are averaged across suppliers and flower colours*

Variation between suppliers

Despite variation in the size and quality of plants delivered from various suppliers, the differences in time to flower initiation were relatively small (Figure 9). In most cases 100% of the plants were floral around the same time, although there were occasions when trays from some suppliers started to initiate more rapidly when compared with those from other suppliers. This was most noticeable in the plants delivered in weeks 32/33. This may well have been due to differences in plant size/age on delivery (appendix 2 and 3).

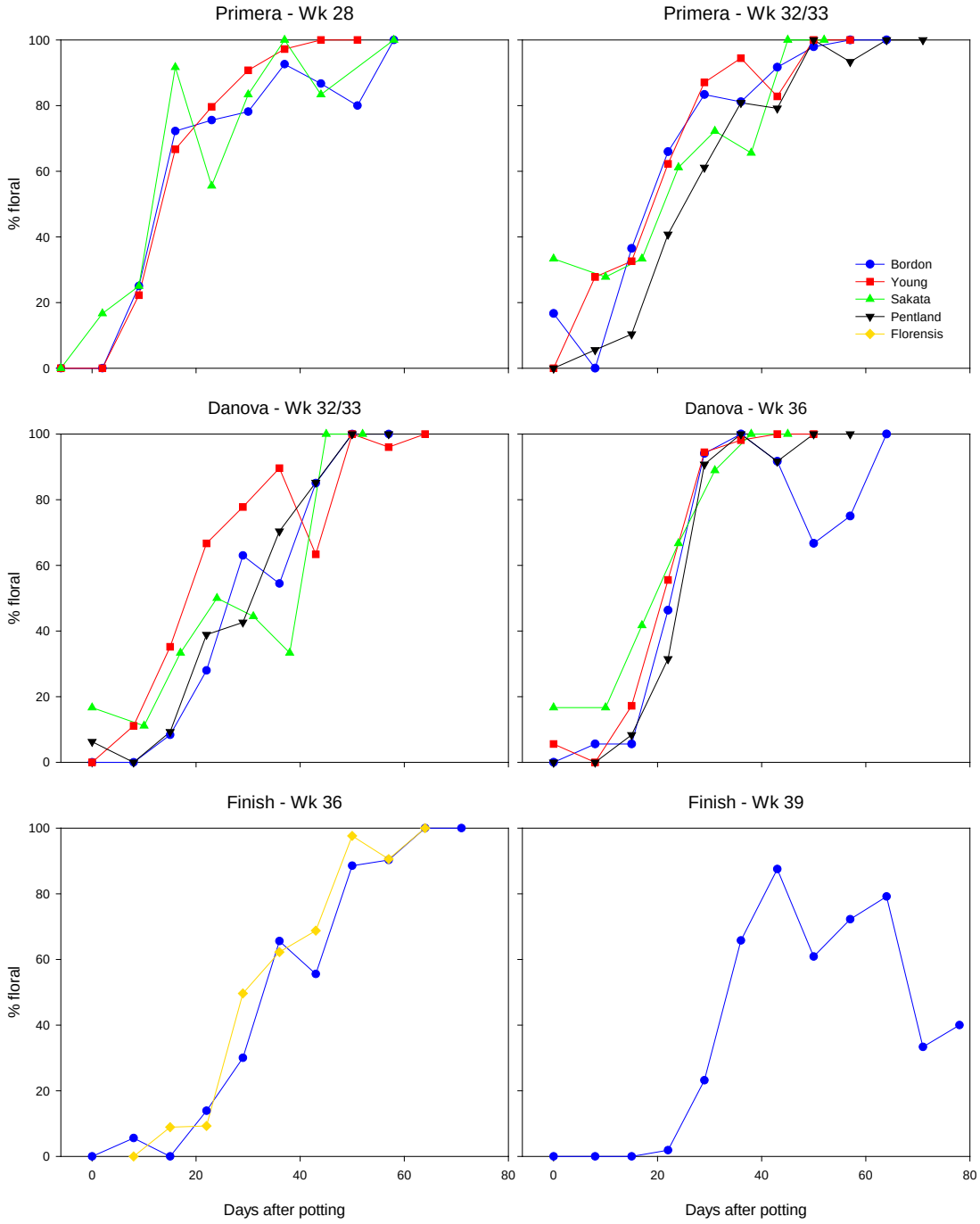


Figure 9. *The effects of supplier on flower initiation. The data are averaged across lighting/shading treatments and flower colours*

Time of flower opening

Effects of series and delivery week

There were significant effects ($P < 0.001$) of series and delivery week on the time of flowering (Figure 10). As expected Primera had the shortest time from potting to flowering (average of 93 days); the week 28 crop being quicker than the week 32 crop. Danova flowered on average 134 days after potting while Finish took on average 169 days. The Finish crops over wintered and the week 36 and 39 crops flowered at a similar time, giving a shorter cropping period for the week 39 crop when compared to the week 36 crop.

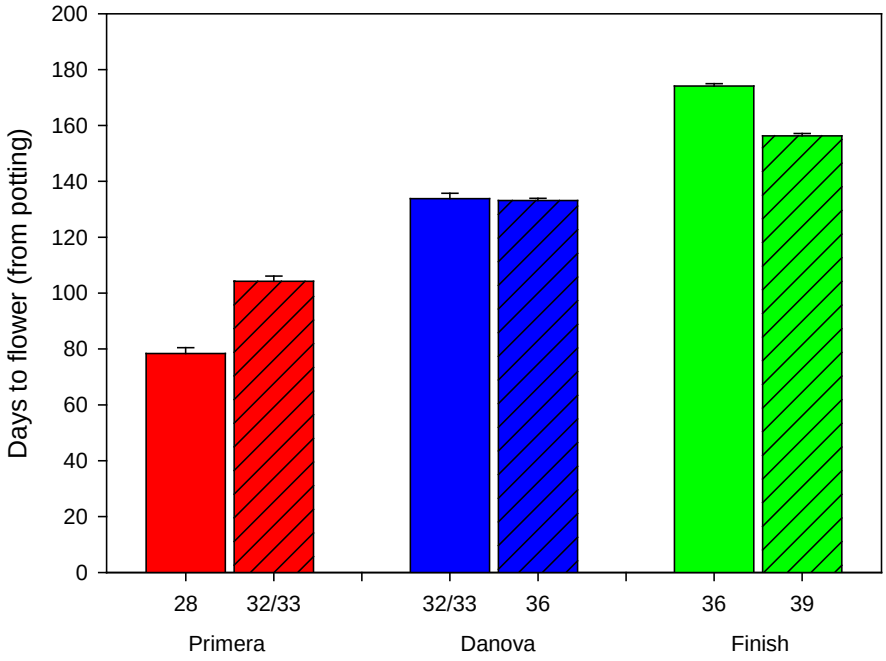


Figure 10. *The effect of series and delivery week on the mean time to flowering (from potting) averaged across suppliers, colours and lighting/shading treatments. The error bars indicate the SEM*

However, as well as affecting the mean flowering time there were differences with regards to the spread of flowering times (Figure 11). The crops delivered in weeks 28 and 32/33 tended to start flowering quickly; however, some plants did not flower until the end of the experiment. For example, Primera delivered in both weeks 28 and 32/33 started to flower at the end of August, and yet some plants did not flower until March..

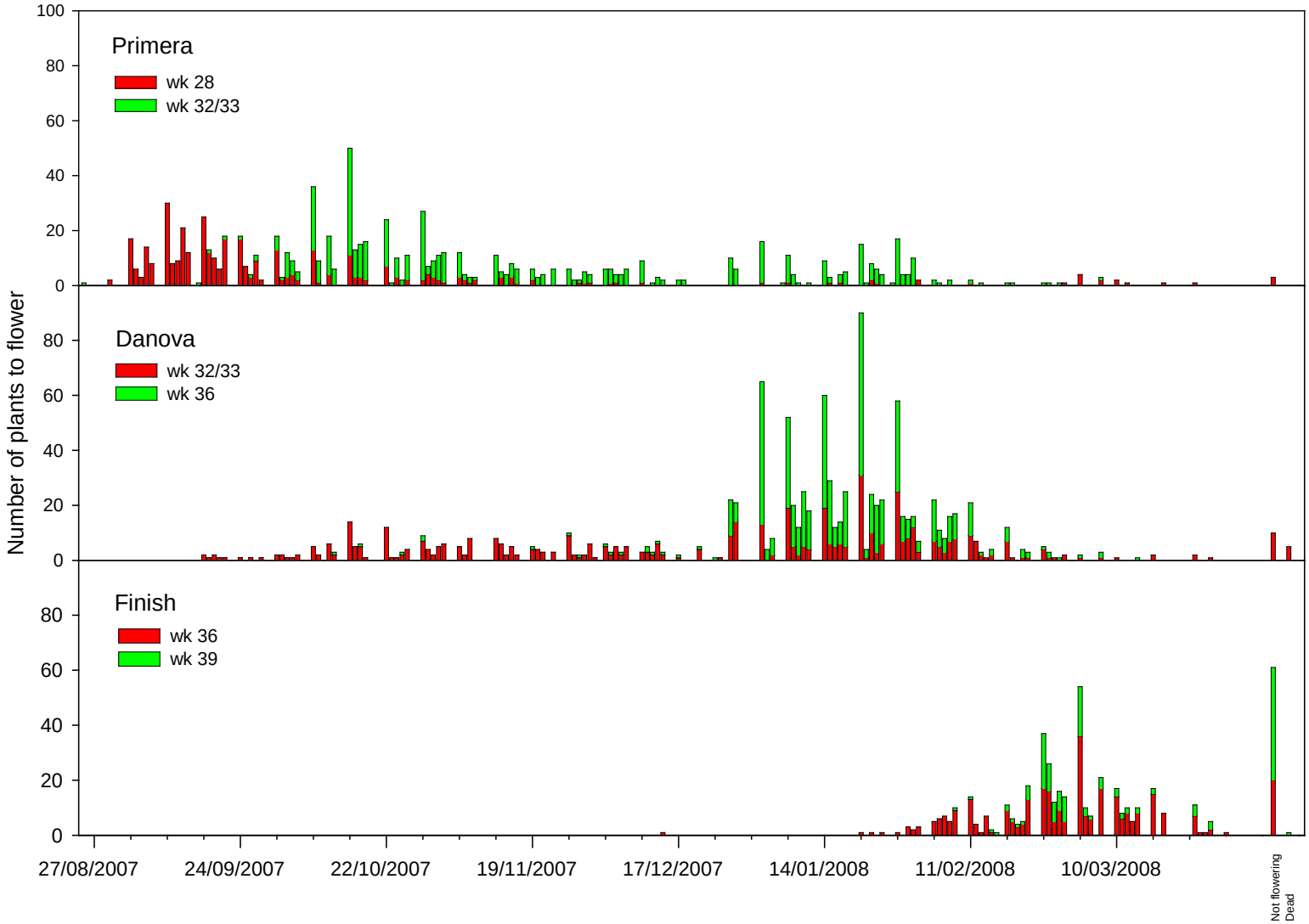

Primera
wk 28
wk 32/33
Danova
wk 32/33
wk 36
Finish
wk 36
wk 39
Number of plants to flower
0
20
40
60
80
100
27/08/2007
24/09/2007
22/10/2007
19/11/2007
17/12/2007
14/01/2008
11/02/2008
10/03/2008
Not flowering
Dead

Figure 11. *The effect of series and delivery week on the distribution of flowering times summed for suppliers, colours and lighting/shading treatments. The final bar shows plants that died or were blind when the experiment ended*

Similarly Danova delivered in weeks 32/33 started flowering on 17 September and continued through until 28 March. In contrast, while the Danova crops delivered in week 36 first flowered on 12 October, most of the plants flowered at a similar time after Christmas. Most of the Finish plants flowered in February and March.

Effects of flower colour

There were significant effects of flower colour on flowering time ($P < 0.001$). For Primera the red flowers tended to be delayed (Figure 12), which was also the case in 2006. However, with Danova the blues flowered first which differs from the results in 2006. The mixed Danova was delayed in relation to the other colours. While the mixture contained other colours, they were not noticeably slower, and so the delay is more likely to be an issue to do with this specific tray. In Finish, the blue flowers were delayed slightly in relation to the yellow and red flowers.

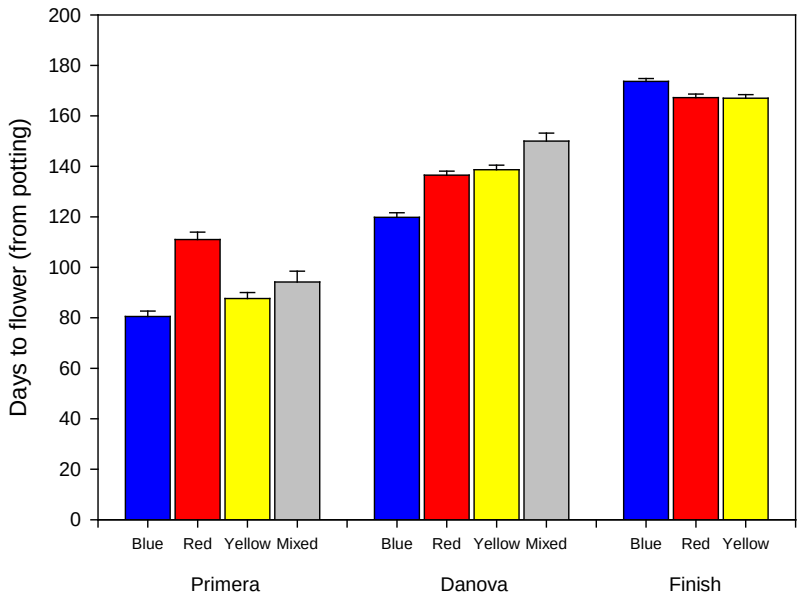


Figure 12. *The effect of series and flower colour on the mean time to flowering (from potting) averaged across suppliers, delivery week and lighting/shading treatments. The error bars indicate the SEM*

Effects of lighting/shading treatments

As with the dissection data, the effects of the lighting treatments on the time to flower differ from those seen in previous years. While shading delayed flowering in Finish (Figure 13), the delay was relatively small compared with those observed at STC in 2006/7. The ambient treatment tended to flower first, in the case of Primera and Danova by a mean of 18 days (when compared to the average of the other two treatments). However, this hastening of flowering will in part be a function of the higher mean temperature in this glasshouse compartment (Figure 3); the work at Warwick HRI showed that high temperatures hasten flower development.

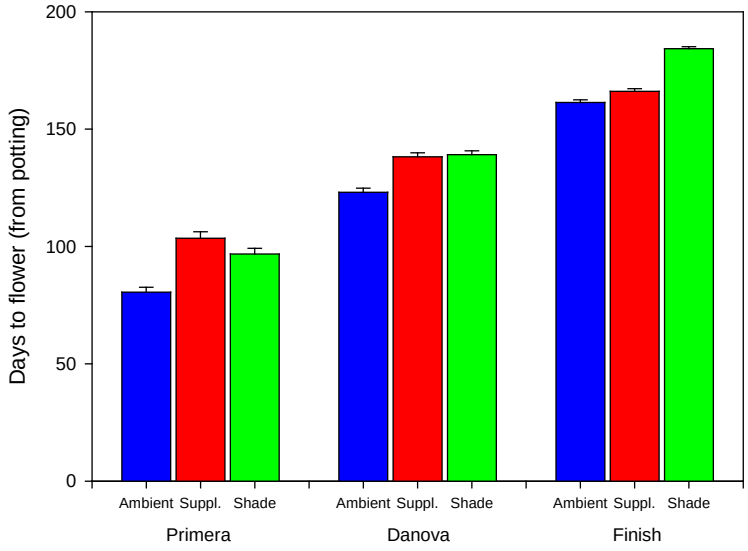


Figure 13. *The effect of lighting/shading treatments and series on the mean time to flowering (from potting) averaged across suppliers, colours and delivery week. The error bars indicate the SEM*

Variation between suppliers

There were differences of up to 27 days in the time to flowering when comparing different suppliers ($P < 0.001$). Plants from Young plants tended to flower slightly

earlier, while the Danova from Sakata, and the Primera from Pentland tended to be delayed slightly (Figure 14).

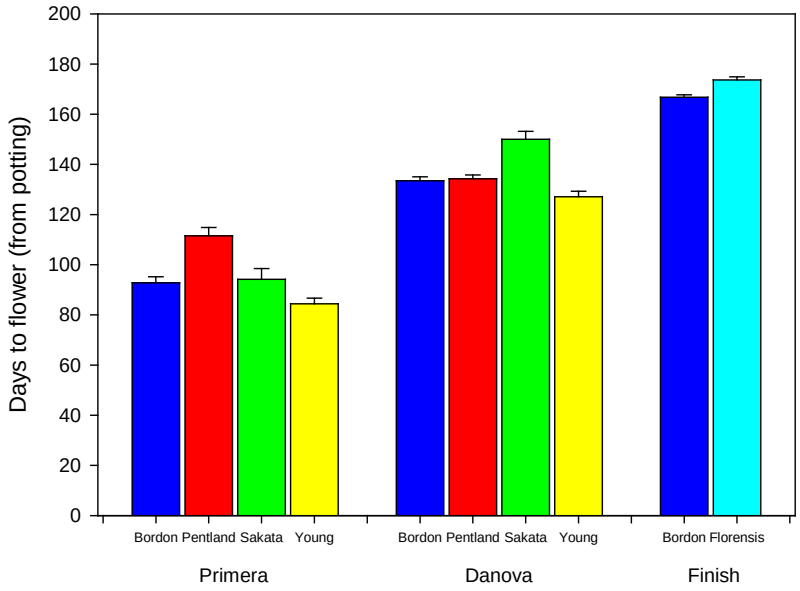


Figure 14. *The effect of series and supplier on the mean time to flowering (from potting) averaged across delivery weeks, colours and lighting/shading treatments. The error bars indicate the SEM*

Commercial nurseries compared with STC

Environmental conditions achieved

Over the period from the 9 August to 19 February, the temperatures at Avoncross and Coletta were very similar (Avoncross was on average 0.8°C warmer). However, the temperature in the ambient compartment at STC was much higher during the latter half of the experiment (Figure 15). As a result the average temperature at STC was 3.7°C warmer than at Coletta.

The light levels at Avoncross were slightly higher than at Coletta; this difference equated on average to 0.8 mol/m^2/d or 15%. Surprisingly the light levels recorded at STC were slightly higher than those at Avoncross (3% more) and considerable more that at Coletta (18% more). However, the quantum sensors used at STC

were different to those used at the other two sites and it is possible that some or all of this difference may have been due to calibration error.

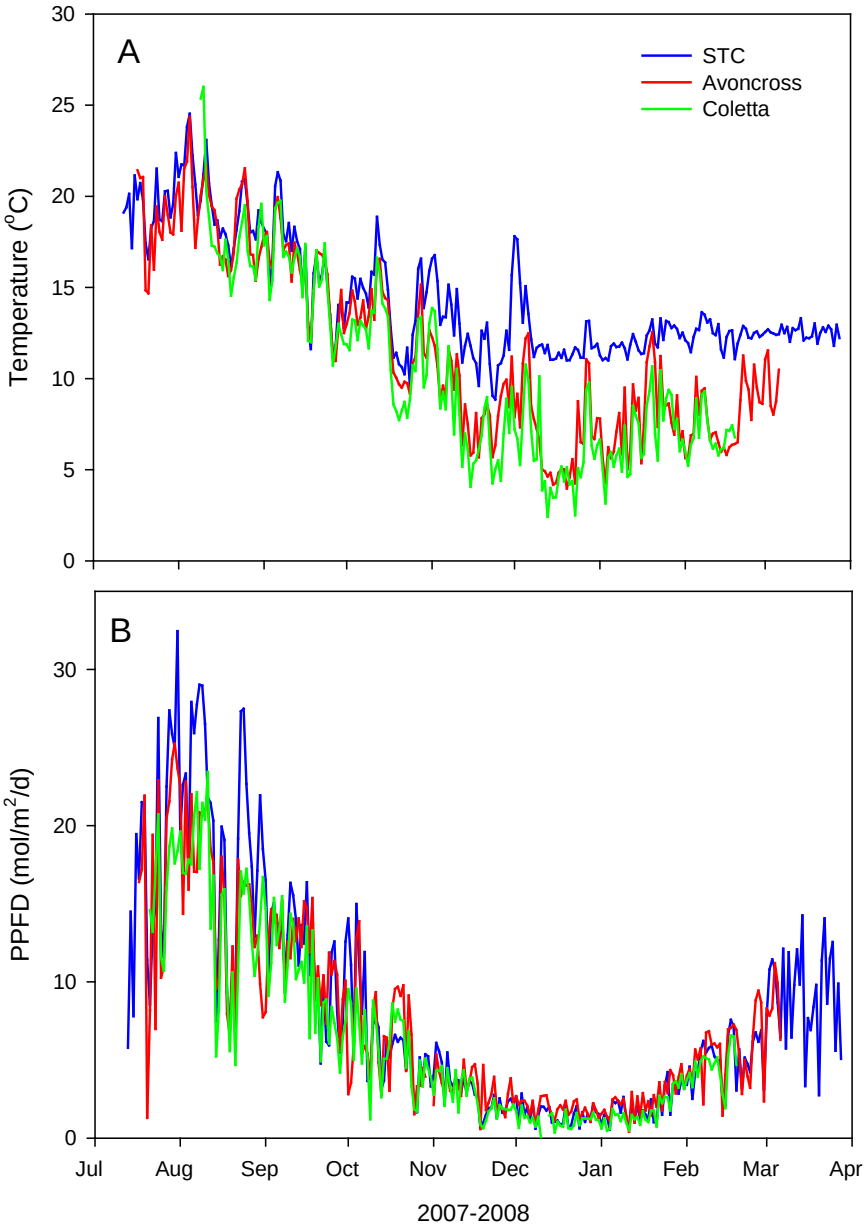


Figure 15. *Mean diurnal air temperatures and light levels (PPFD) recorded in the ambient glasshouse compartment at STC and on the two commercial sites; Coletta and Avoncross*

Time of flower initiation

The time to flower initiation was generally similar at all three sites (Figure 16). On some crops the plants at Coletta started to initiate at a similar time to those at STC and Avoncross, however, there it took a few weeks longer before 100% initiation was observed. Data for the week 32 Danova are not shown for Coletta as these plants were mixed with another commercial crop. There is also some concern over the validity of the week 32 Primera crop at Coletta.

The Finish plants delivered in week 36 initiated slightly earlier at STC. This may have been due to the higher temperatures at STC, although different potting and sampling dates may have also contributed. These plants were also slightly heavier at STC (Figure 17).

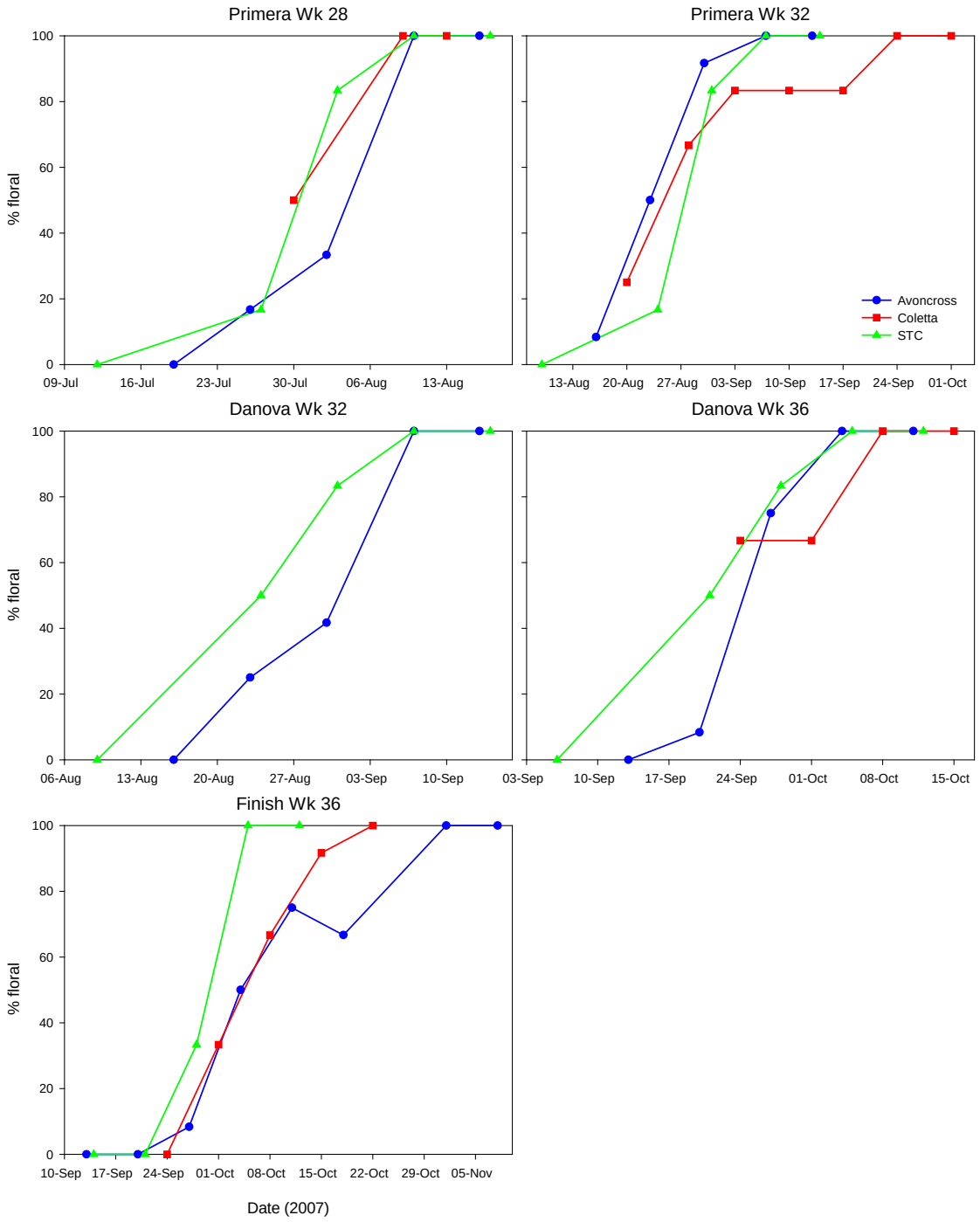


Figure 16. *The effects of site on flower initiation. The STC data are from the comparable yellow Young Plants/Florensis trays grown in the ambient lighting treatment*

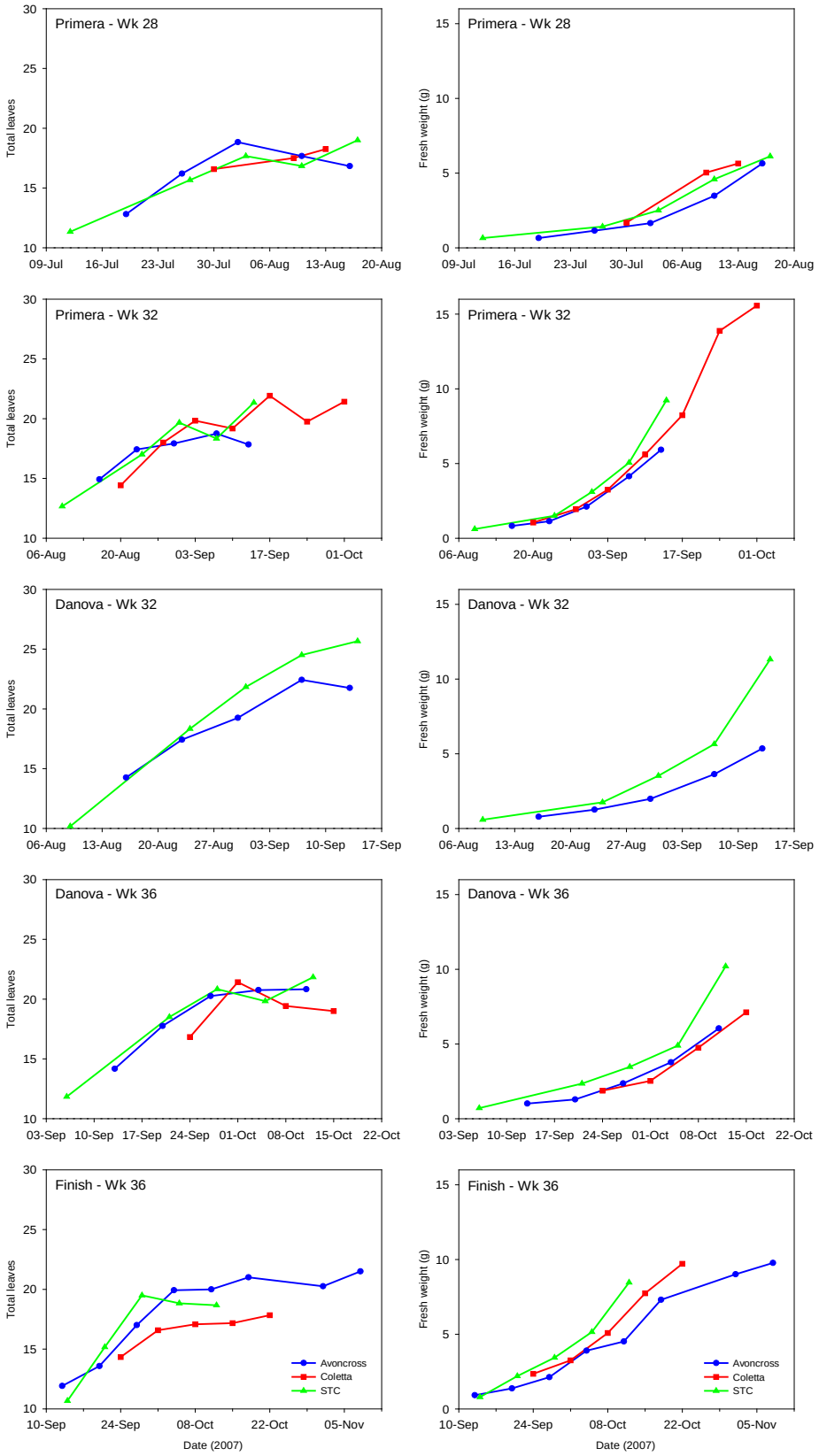


Figure 17. *The effects of site on the shoot fresh weight and leaf numbers. The STC data are from the comparable yellow Young Plants/Florensis trays grown in the ambient lighting treatment*

Time of flower opening

Flowering at Avoncross appeared to be in the order of a couple of weeks earlier than at Coletta (Figure 18). This may have been due to the slightly higher light levels recorded at Avoncross (Figure 15B). Plants grown at STC also flowered earlier than those at Coletta. The higher light levels recorded at STC may be due to sensor differences and the temperature difference between the Coletta and STC sites is perhaps more likely to have caused the earlier flowering. The plants at STC tended to flower within a week or so of those at Avoncross.

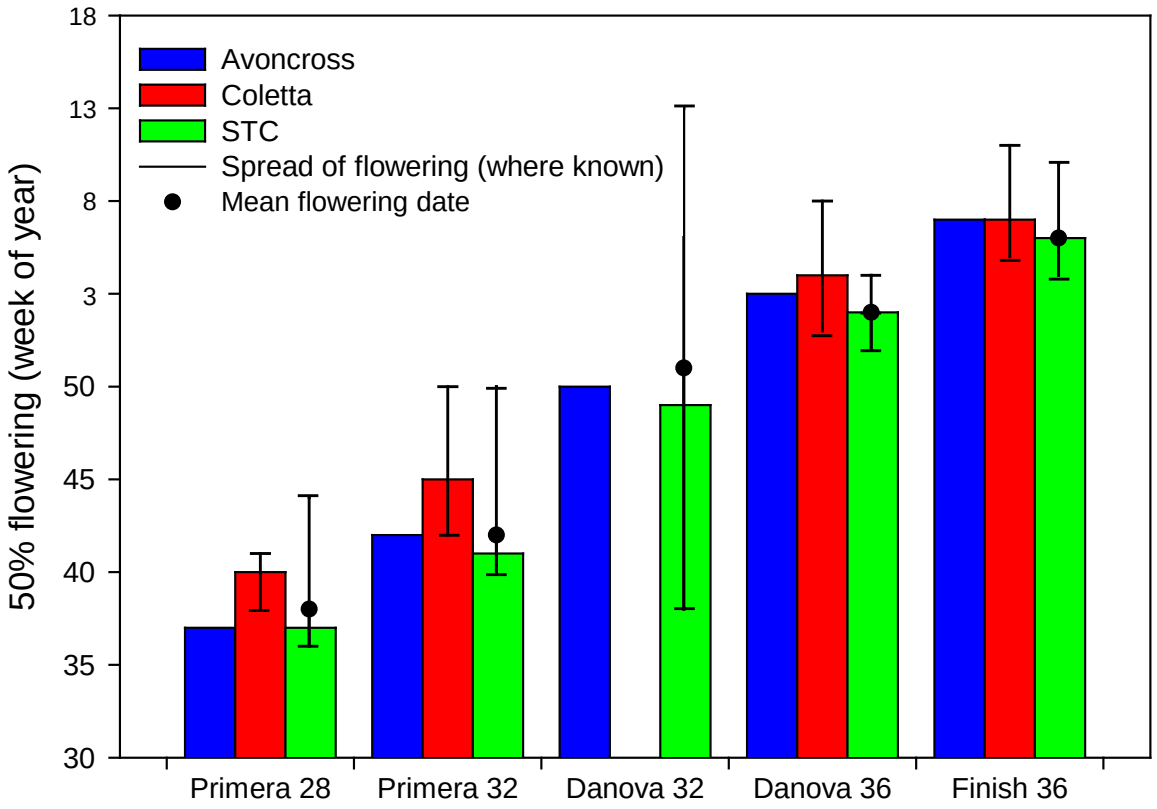


Figure 18. *The time to 50% flowering (median) at each site. The spread of flowering is shown by the bar which indicates first flowering to full flower. The STC data are from the comparable yellow Young Plants/Florensis trays grown in the ambient lighting treatment and in this case the mean flowering time is also shown*

Model validation

Model description

The data presented in this report were used to independently test the models that were presented in the 2006 Annual Report. The number of days from the start of the treatments at Warwick HRI (19 or 20 days from sowing) to when 100% of the plants dissected were floral (D_l) was described by the following equation:

$$1/D_l = a + b.T_{eff} + c.PPFD + d/PPFD^2$$

(eqn. 1)

where *a*, *b*, *c*, and *d* are cultivar dependent constants, *PPFD* is the average light level (mol/m^2/d) from the start of treatment and the effective temperature (T_{eff}) is calculated as:

$$T_{eff} = T_{opt} - |T_{opt} - T|$$

(eqn. 2)

where T_{opt} is the optimum temperature (°C) at which the rate of progress to initiation is greatest and T is the actual mean temperature (°C) from the start of the treatment. The optimised values are shown in Table 3.

Table 3. *Optimised model parameters for the model of time of flower initiation (eqn. 1).*

Parameter	Parameter values (± standard error)

	Primera （Quantum）	Danova	Finish
a	-0.00345 （±0.00395）	-0.008 （±0.00436）	-0.00456 （±0.00425）
b	0.001014 （± 0.000265）	0.00143 （±0.000259）	0.001092 （±0.000279）
c	0.000808 （±0.000188）	0.000526 （±0.000172）	0.000516 （±0.000186）
d	-0.01383 （±0.0037）	-0.01491 （±0.00348）	-0.01355 （±0.00364）
T_{opt}	15.0 （±0.59）	15.8 （±0.34）	15.6 （±0.46）

The initiation models were run using Visual Basic in Excel. As the STC and commercial trials involved using mature plugs （rather than small seedlings as at Warwick HRI）, it was assumed that all of the plugs were 20% of the way to flower initiation at the time of potting up. This was done to simplify the model by avoiding the need to enter environmental data for the plug production phase. The calculations were made on a daily time step. Average temperatures and light levels from potting to any given date were calculated and used to predict the average rate of progress to flowering. The average rate was then multiplied by the number of days from potting and flower initiation was predicted to occur on the day when this first summed to one.

A similar approach was used for flower development. Based on the data from Warwick HRI, the number of days from 100% initiation to the mean date of flower opening （D_F） was described by the following equation:

$$1/D_F = a.T + b.PPFD \qquad \text{(eqn. 3)}$$

where *a and b* are cultivar dependent constants, *PPFD* is the average light level （mol/m^2/d） over the period and *T* is the mean temperature （°C） over the period. The optimised values can be seen in Table 4.

Table 4. *Optimised model parameters for the model of flower development (eqn. 3)*

Parameter	Parameter values (± standard error)		
	Primera (Quantum)	Danova	Finish
a	0.000803 (±0.0000527)	0.000599 (±0.0000555)	0.000455 (±0.0000519)
b	0.001519 (±0.000147)	0.001286 (±0.000146)	0.001129 (±0.000138)

The flower development models were run using Visual Basic in Excel. The calculations were made on a daily time step from 100% initiation, based on the average temperatures and light levels from initiation to any given date. The average rate was then multiplied by the number of days from flower initiation and the mean flowering time was predicted to occur on the day when this first summed to one. Furthermore, this model was combined with the flower initiation model so that flowering time could be predicted from potting up without the need to input dissection data.

Model predictions for the STC crops

While the models were developed based on yellow crops grown at Warwick HRI, as the differences between colours were not that great, and were not consistent, the models were not recalibrated for each colour. Instead the simulated initiation and flowering times (based on the model for yellows) were compared with the responses averaged across all flower colours and suppliers.

The predictions of the time of flower initiation were generally within two weeks of the times observed by dissecting plants (Figure 19). This is reasonably accurate given that the inherent inaccuracies with the plant dissections and the fact that

these were only carried out on a weekly basis. The model predictions were slightly less accurate with some of the week 36 and 39 crops which occasionally initiated over winter, rather than waiting until the spring as predicted by the model. Furthermore, the shaded crops were sometimes predicted to initiate slightly later than they did.

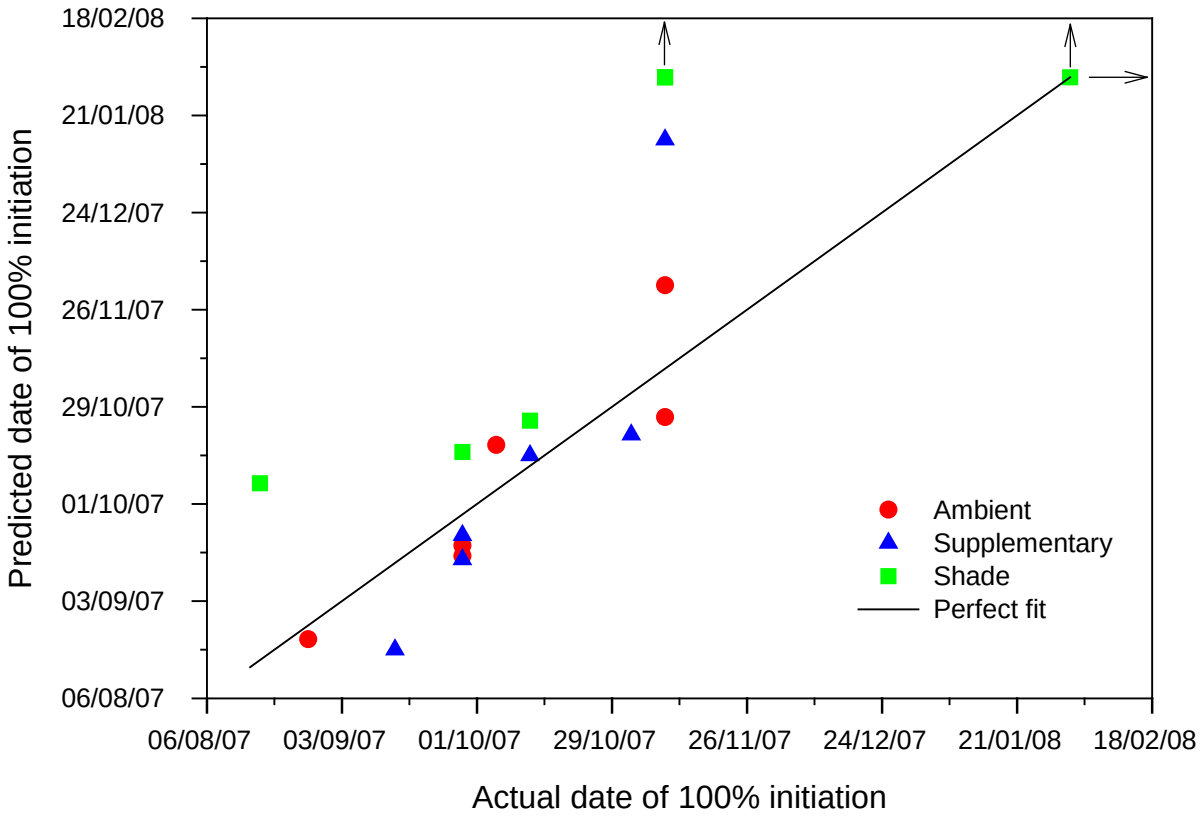


Figure 19. *Comparison of when 100% of plants were estimated to have initiated based on dissections (actual) with dates predicted using the model. The actual dates are averaged across flower colours and suppliers. Arrows indicate where the initiation was later than the value shown*

When the flower initiation and flower development models were combined to predict the mean flowering time, the ambient predictions were generally very close (Figure 20), especially given the assumptions made in the model and the spread of flowering times. However, the lit plants were predicted to flower earlier than was the case and the shaded plants were predicted to flower later than was the case. This variation between the model and measurements is not surprising given that the

response to shading in this trial was very small when compared to the previous trials.

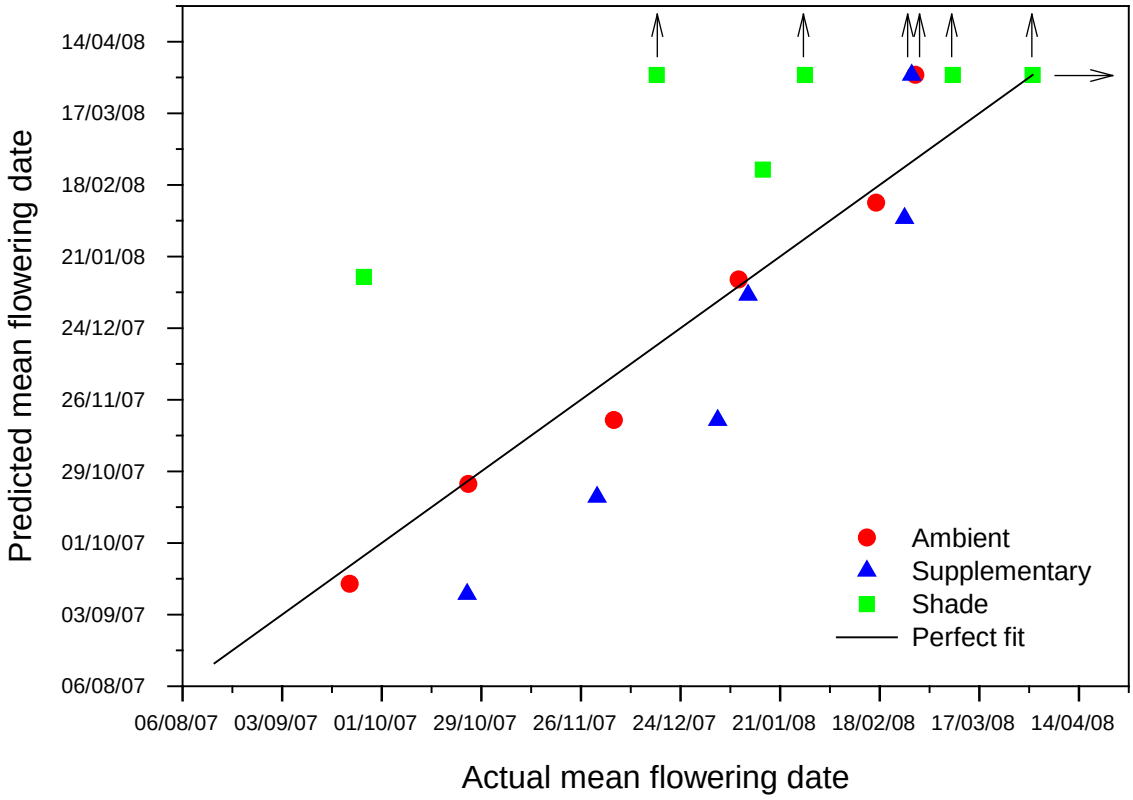
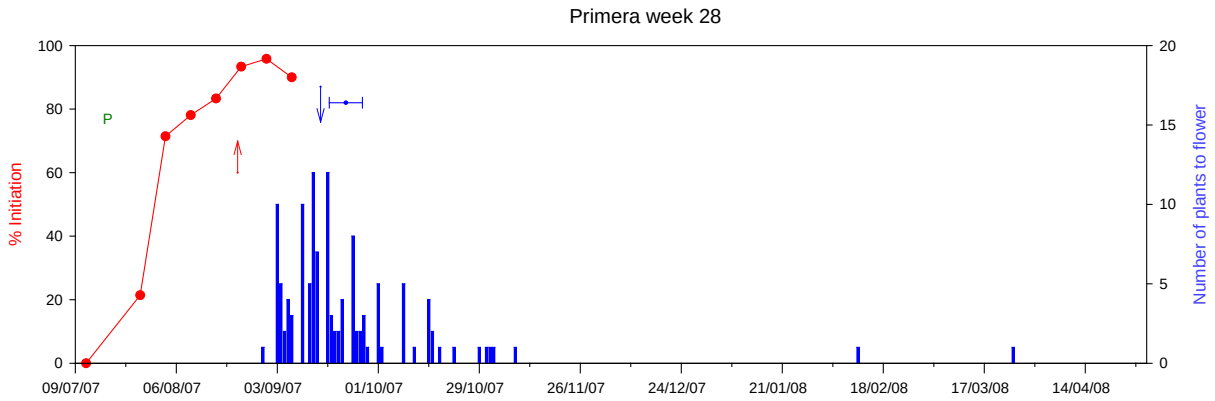
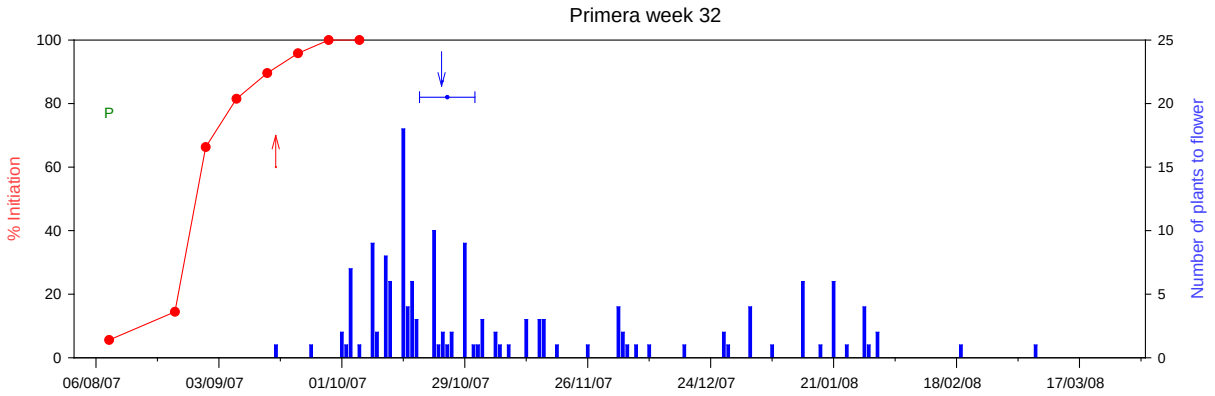
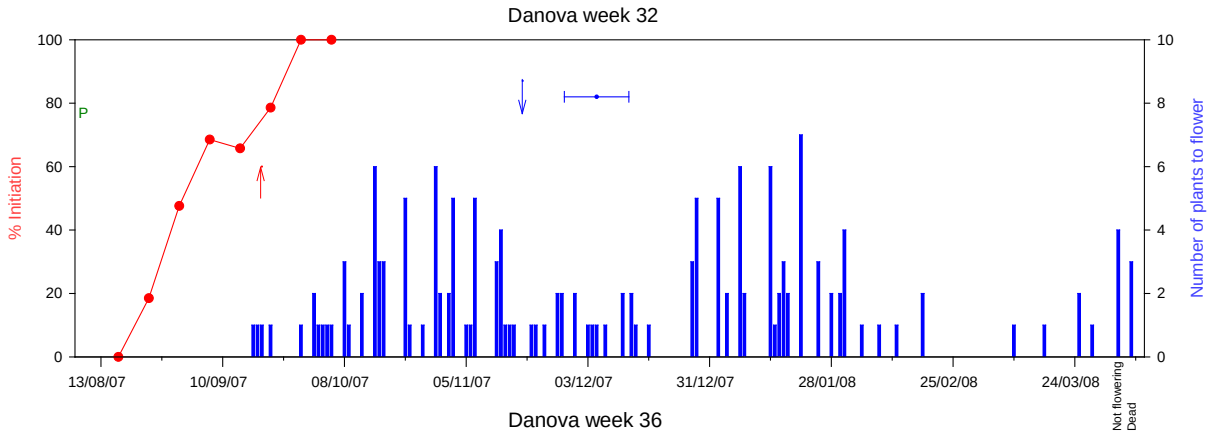


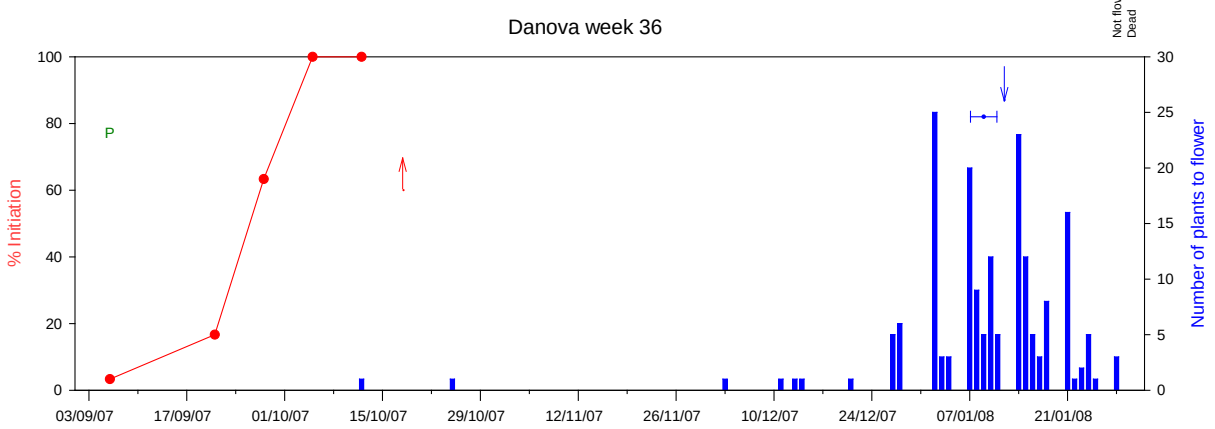
Figure 20. *Comparison of the mean flowering date (averaged across flower colours and suppliers) with the mean flowering date predicted using the model. Arrows indicate where flowering was later than the value shown*

The predictions for the ambient crops are shown in more detail in Figure 21. These figures show the predicted flower initiation and flowering times in relation to the development of the crop in terms of initiation and flower opening. The crop where the model was least accurate is for the Finish delivered in week 39. The light levels were predicted to push the crop later than was the case.









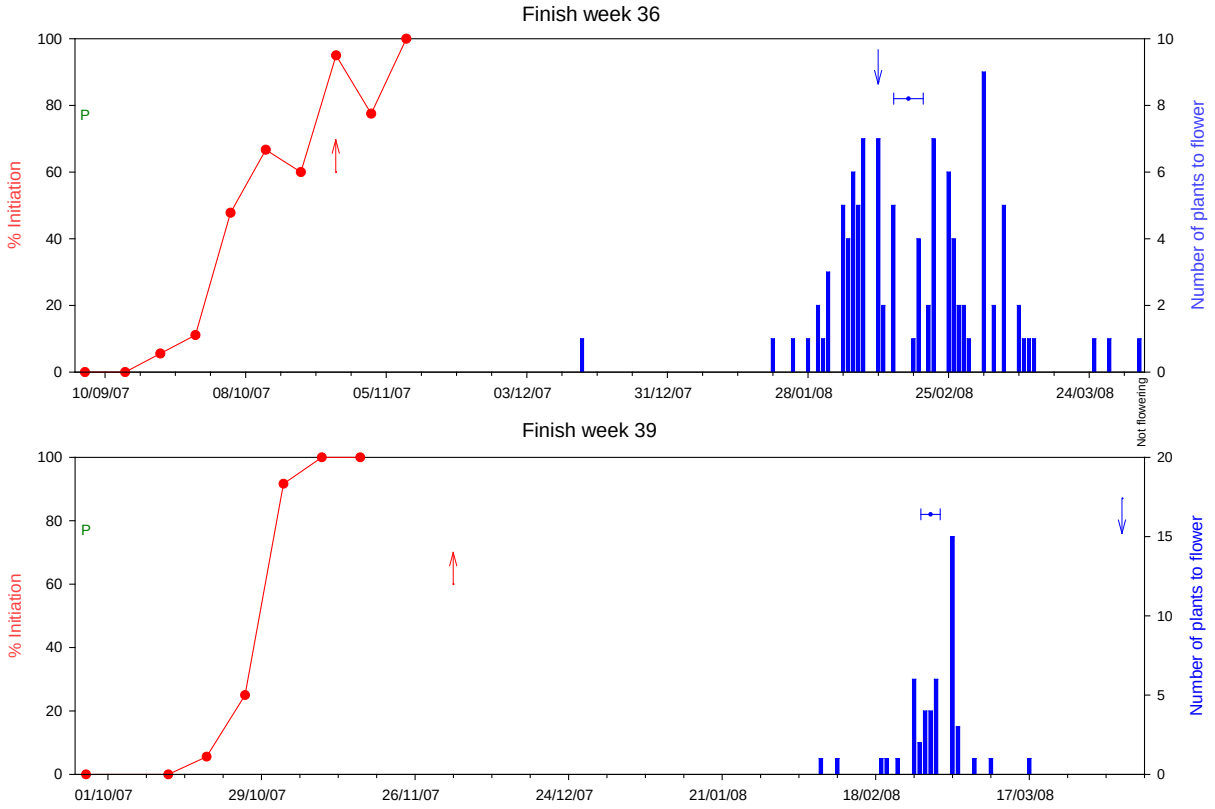


Figure 21. *Predicted and actual deleopment of the ambient crops at STC. The red points indicate the percentage of plants that have initiated in any given week based on apical dissections, while the red arrow indicates the time that the model predicted 100% initiation was likely to occur. The blue bars indicate the number of flowering plants per day and the blue dots and error bars indicate the mean flowering time and the LSD (5%) of this estimate, respectively. The blue arrow indicates the mean flowering time predicted by the model (based on the predicted rather than actual initiation times). P indicates the time of potting up*

Model predictions for the commercial crops

The model was tested in the same way using the data from the commercial crops. The time at which 50% flowering was observed was compared with the predicted mean flowering time (Figure 22). The predictions for crops at Avoncross were accurate within two weeks for all crops except the week 36 Finish which flowered

around a month earlier than predicted by the model. Similarly the flowering times of first crops at Coletta were predicted to within a week, while greater errors occurred with the crops that were delivered in week 36.

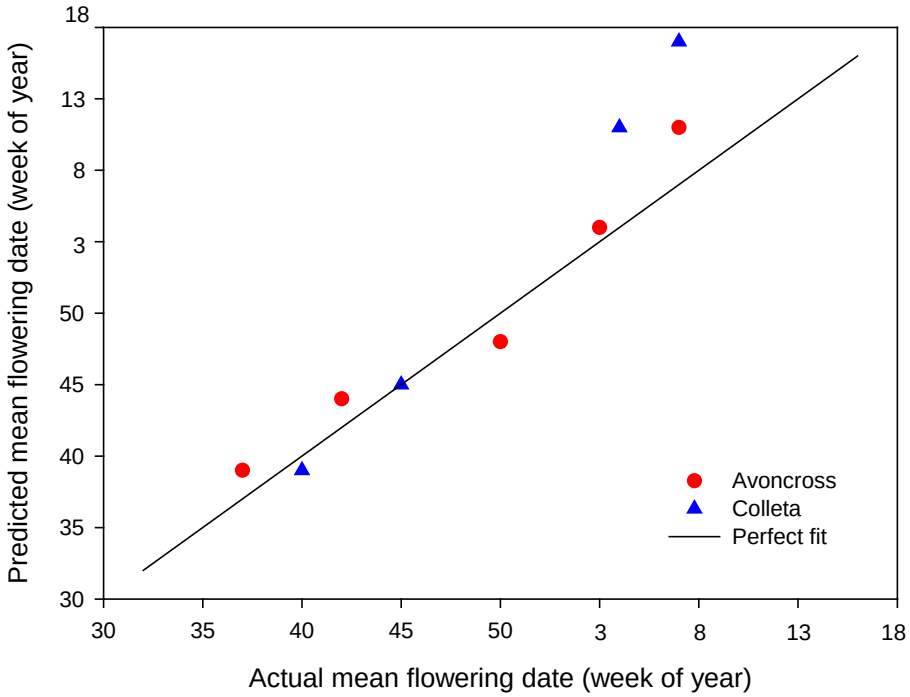


Figure 22. *Comparison of the estimated 50% flowering date with the mean flowering date predicted using the model for both commercial sites*

Discussion

While there were differences between flower colours, the data tend to suggest that it is not unreasonable to use the same flowering model (developed for yellows) to predict for all colours in the series. This is backed up by the fact that the colours did not flower in the same order in the two STC trials. Furthermore, the differences between suppliers were not so great so as to rule out the use of a general model for plugs of a given series. Clearly variability between plug trays will cause differences in flowering time which will result in deviations from the flowering time predicted by the model. However, the simplicity of this approach is highly

advantageous; it would be difficult for most growers to gain sufficient background information on plugs so as to be able to run the model from seedling emergence. Here we assumed that all of the plugs were 20% of their way to 100% initiation at potting up. This proved to be a reasonable estimate, although will clearly be a cause of some errors.

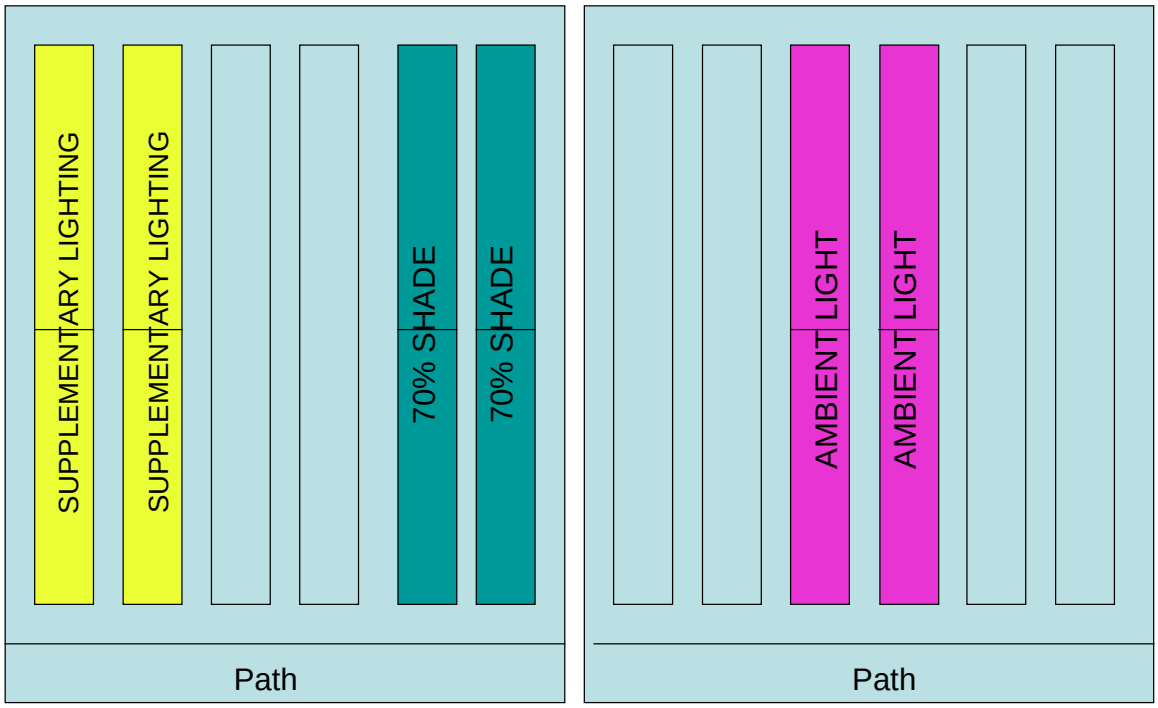
While the model was able to predict the time of initiation and flowering with a reasonable degree of accuracy for many crops, the effects of the shading and lighting treatments were not predicted accurately. However, this was not surprising given that the effects of lighting and shading were different to those that have been observed in previous trials (on which the model was derived). Considerable delays were seen as a result of shading in the initial trials at Warwick HRI. However, in these trials the plants were grown under shaded conditions from seedling emergence and so the treatments affected the plugs which may have been carried over following potting. Nevertheless shading also had a marked effect in the 2006/7 trial at STC when treatments were not imposed until potting on. Therefore, there is some uncertainty as to why the results differ over years and this needs to be resolved before the model can be modified to take account of this.

The early delivery dates were often predicted more accurately than the later delivery dates. One cause could be due to changes in the genetic material used to make up the series. However, a more likely explanation might be that the work at Warwick HRI showed that plants were very sensitive to low light levels and that this (in combination with temperature) was the primary cause of blindness. Therefore the models are very sensitive to small changes in light and therefore light measurement errors can cause large differences in the predicted time to flowering. Furthermore, a small change in the predicted time of initiation in autumn can cause a large difference in flowering time in winter/spring. This is an area where the

model could probably benefit from slight recalibration if sufficient commercial data were available.

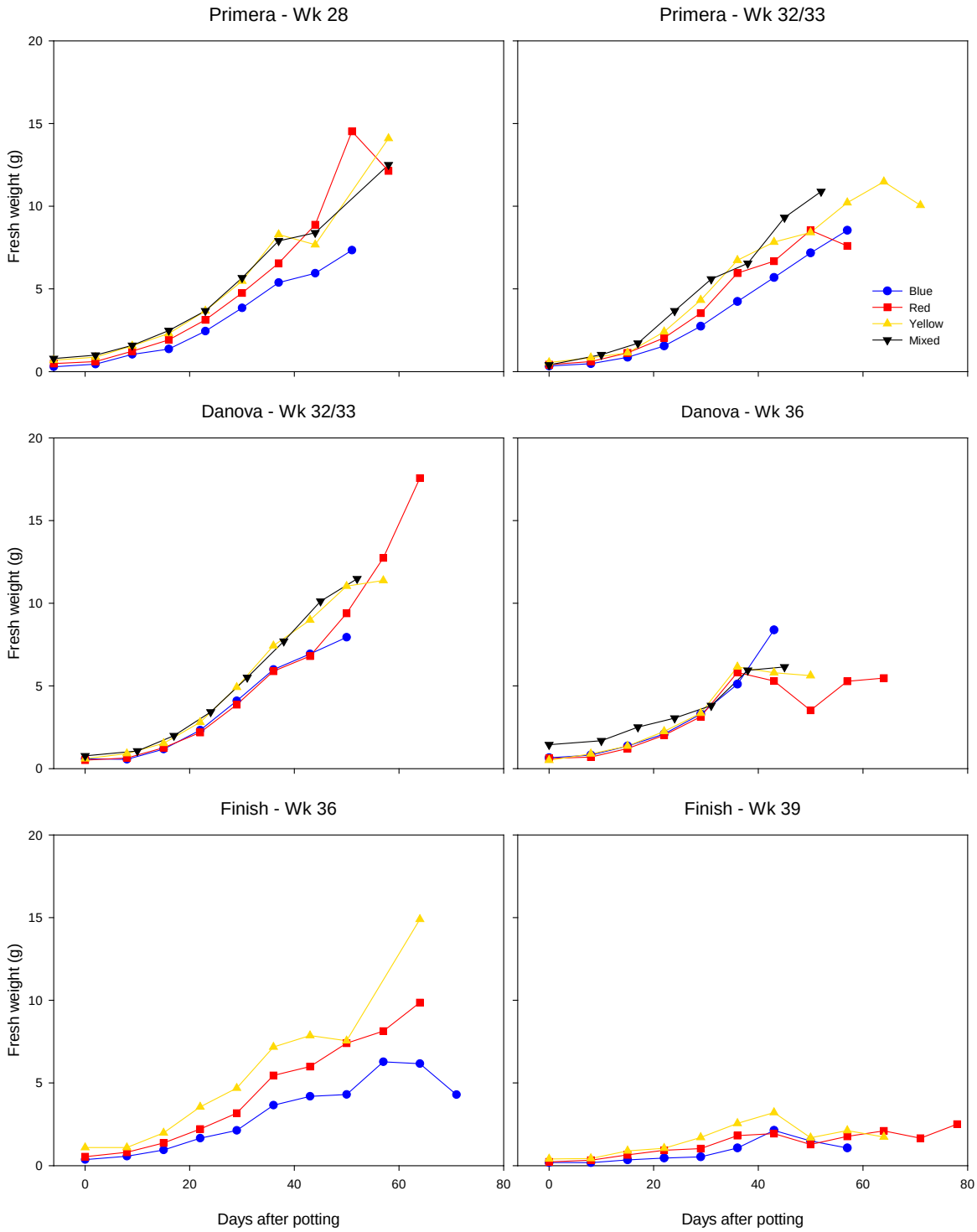
There was considerable variability in the spread of flowering. For some crops flowering occurred over several months. In the case of the Primera at STC flowering was spread over a six month period. Therefore the accuracy of the flowering model needs interpreted with this in mind. Furthermore, with a wide flowering spread there may be differences between what is considered marketable and mean flowering time predicted by the model.

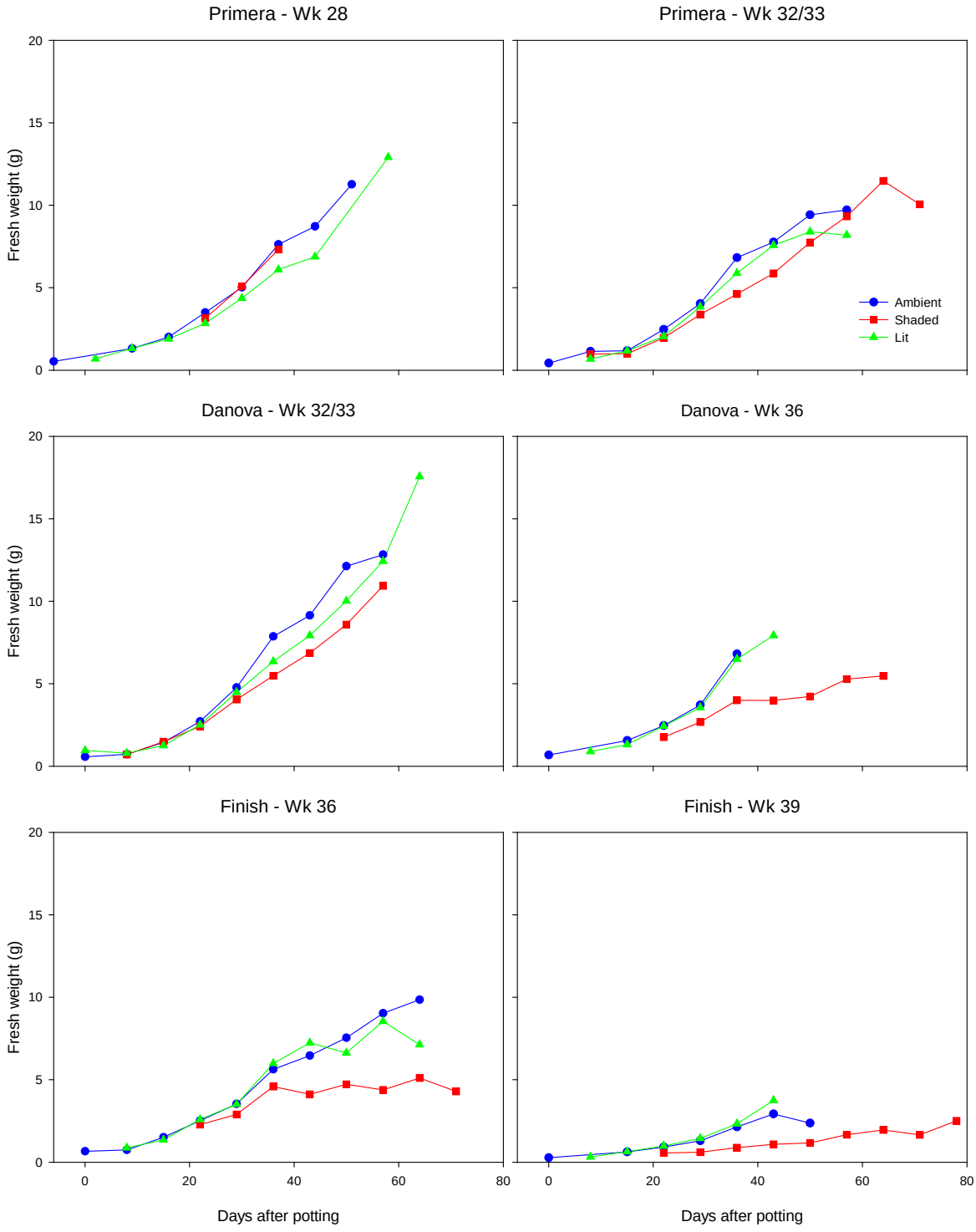
Appendix 1 – Experimental plan at STC:

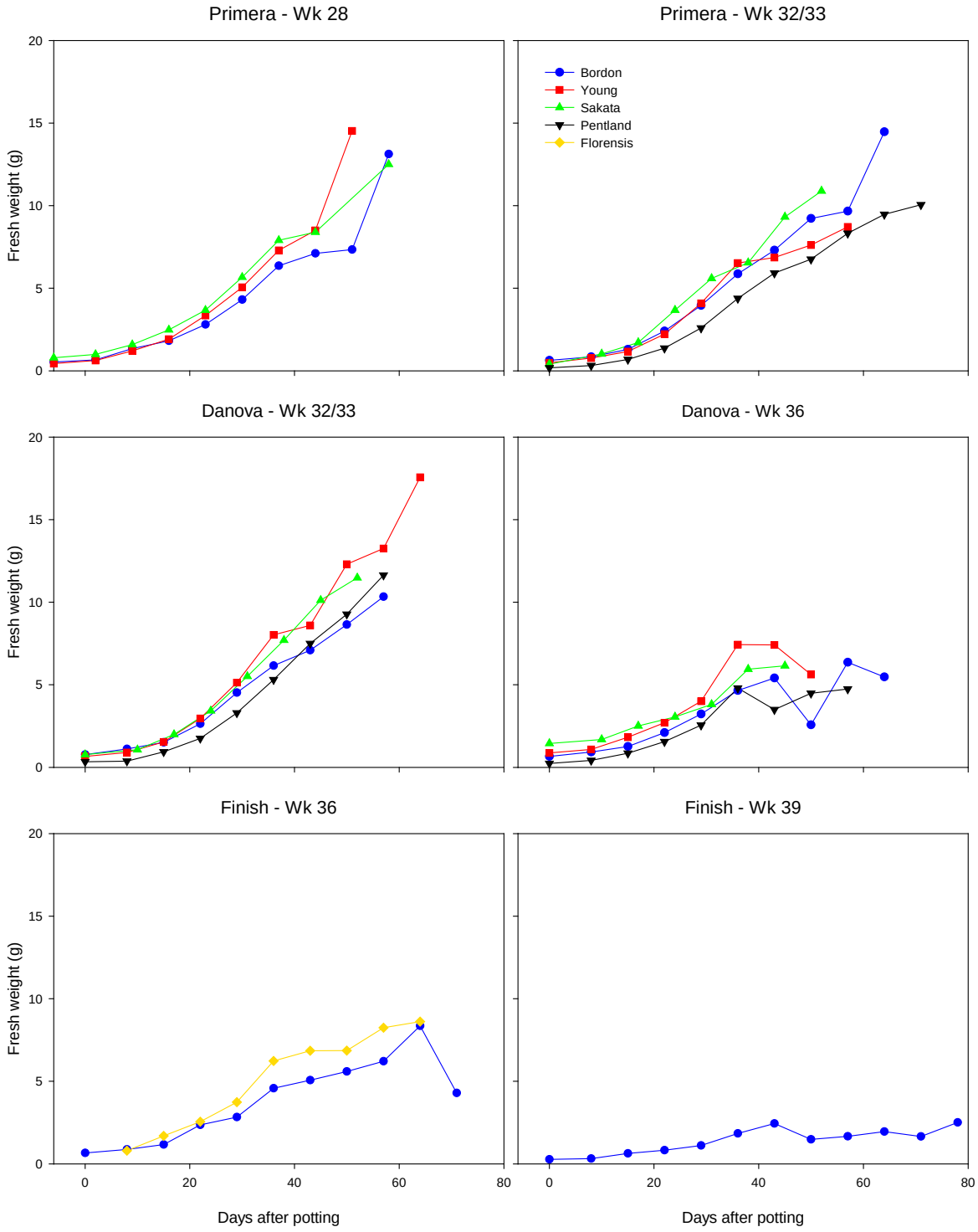


Glasshouse Corridor

Appendix 2 – *The effect of flower colour, lighting/shading treatment and supplier on the increase in shoot fresh weight*







Appendix 3 – *The effect of flower colour, lighting/shading treatment and supplier on the increase in the total number of leaves (visible and macroscopic)*