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PRACTICAL SECTION FOR GROWERS

Cineraria (*SenecioH hybridus* Hyl.) is a popular pot plant crop grown overwinter in a diverse range of structures, from frost protected polytunnels to heated glass. There has recently been renewed commercial interest in this crop, since multiples view it as an attractive alternative winter/spring flowering crop to main stream items such as pansy and primrose. However, traditional cineraria cultivars have been notoriously difficult to schedule and programme. This has prevented retailers stocking the succession of crops required to develop a build in demand. However, recent breeding has led to the development of the Venezia range of colours, which are reputed to flower reliably and consistently between successive batches. This claim has not been tested, as an extensive examination of the factors affecting flowering in this cultivar has not been conducted. There is also considerable interest in developing improved production schedules for other commercially important cultivars.

In order to develop effective and reliable plant scheduling strategies, a full understanding is required of the environmental factors governing the progress to flowering. However, the effects of the environment on flowering in cineraria have yet to be fully resolved to the point at which schedules can be developed and tested. This was the main objective of this study.

Experiments were conducted at two locations, Reading and HRI Efford. The work at Reading focussed on detailed experiments to determine when the flowers initiate. Experiments also examined effects of temperature and sowing date on time to flowering and its variability. The three varieties examined were Meteor, Venezia and Star Wars.

Factors affecting flower initiation in Cineraria

Previous studies have suggested cineraria require cool temperatures to initiate, followed by warmth for flower development. Interactions with other environmental factors have yet to be fully resolved. The first phase of experiments at Reading therefore composed of detailed studies to determine how temperature, light level and day length affect the time to the microscopic initiation of flowers. Figure A shows the effects of temperature and photoperiod on the time to flower initiation in Venezia. This shows that time to flower initiation was highly dependent upon both day length and temperature, with time to initiation varying between 55 to 134 days depending upon treatment.

- Under short days (8 to 11h d^{-1}) time to flower initiation was most rapid at the coolest temperature (9.4°C). Warmer temperatures led to a delay in flower initiation, and the sensitivity to temperature was considerable, plants at 11 hd^{-1} at 20.3°C took twice as long to initiate flowers as those at 9.4°C.
- Under long days, time to flower initiation was less dependent upon temperature, but earliest flower initiation occurred at intermediate temperatures (12.7 to 16.7°C).
- The main differences between the varieties were that Star Wars was much less sensitive to short days for flower initiation. Thus, at approximately 9°C Venezia required 55 days to initiate at 11hd^{-1} and 115 at 17hd^{-1} whilst Star Wars required 88 and 125 days, respectively. In terms of the temperature response Star Wars did not initiate any flowers when temperatures exceeded 17°C, and then they were very late (145 days, compared to 124 with Venezia). Venezia initiated even at 20°C. *This suggests that the large response to short days and rapid flowering at warmer temperatures in Venezia will make the variety capable of flowering during both the summer and winter months.*

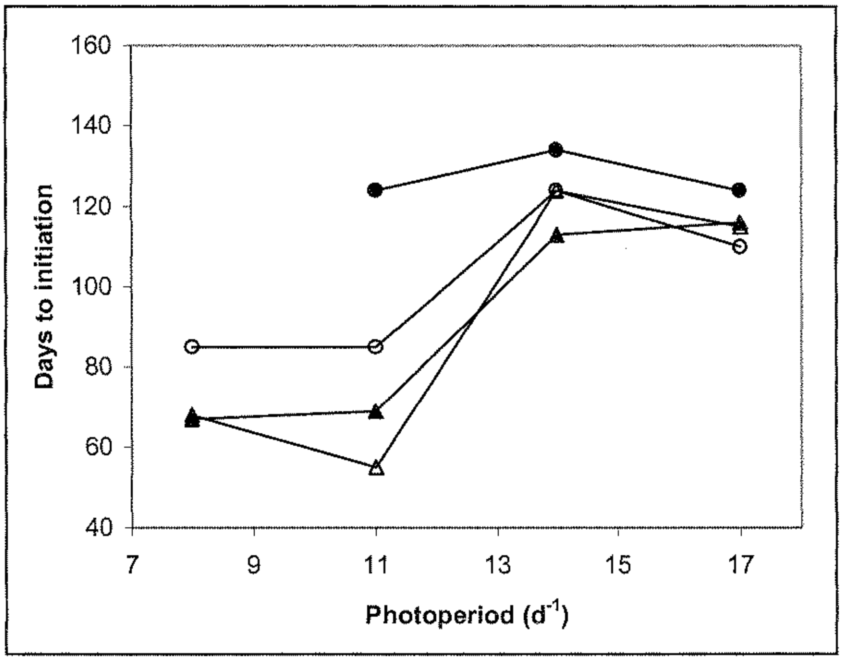


Figure A. The effects of photoperiod and temperature (20.3°C (●); 16.7°C (○) 12.7°C (▲); 9.4°C (△) on time to flower initiation in Venezia.

Factors affecting flower development in cineraria

A second experiment examined how environment following flower initiation affected the rate at which flowers develop. In this instance, the response to environment completely changed, (see Figure B).

- Short days tended to delay time to flowering (from initiation to opening), such that plants grown at 8h d^{-1} and the warmest temperature flowered 10 days later than those at 17hd^{-1}. The short day delay was more marked with Star Wars and Meteor, where the comparable delay was 40 days at the shortest compared to longest photoperiod.
- Warm temperatures promoted flower development, with plants at 9.5°C flowering on average 30 days later than those at 20°C.

These data on flower initiation and development demonstrate the highly complex linkage between environment and time to flowering in cineraria.

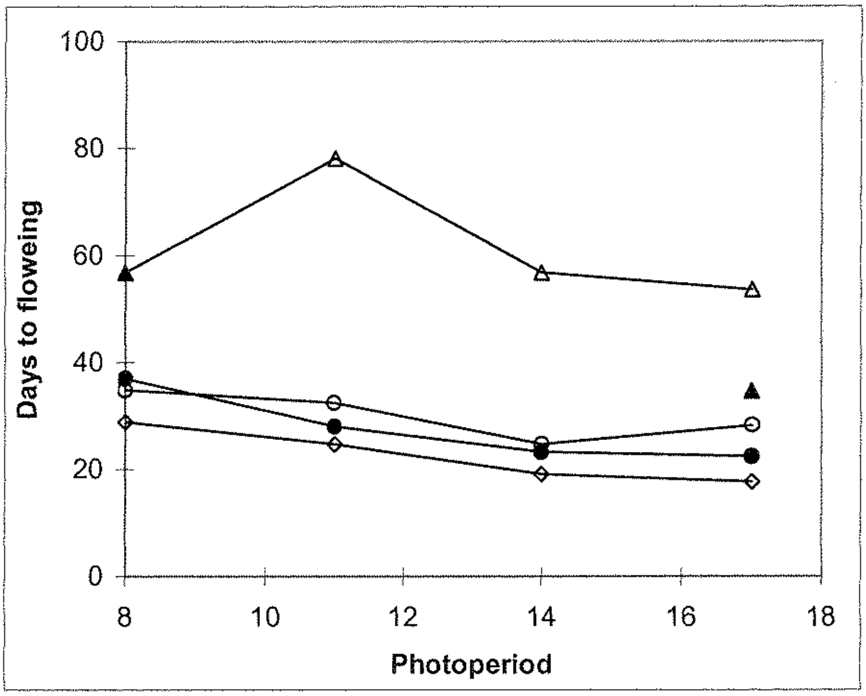


Figure B. Effects of photoperiod and temperature (23.8°C (◊); 20.3°C (●); 16.7°C (○); 12.7°C (▲); 9.4°C (△)) on duration of flower development in cv. Venezia, measured from time of initiation.

Scheduling flowering in cineraria – some preliminary guidelines

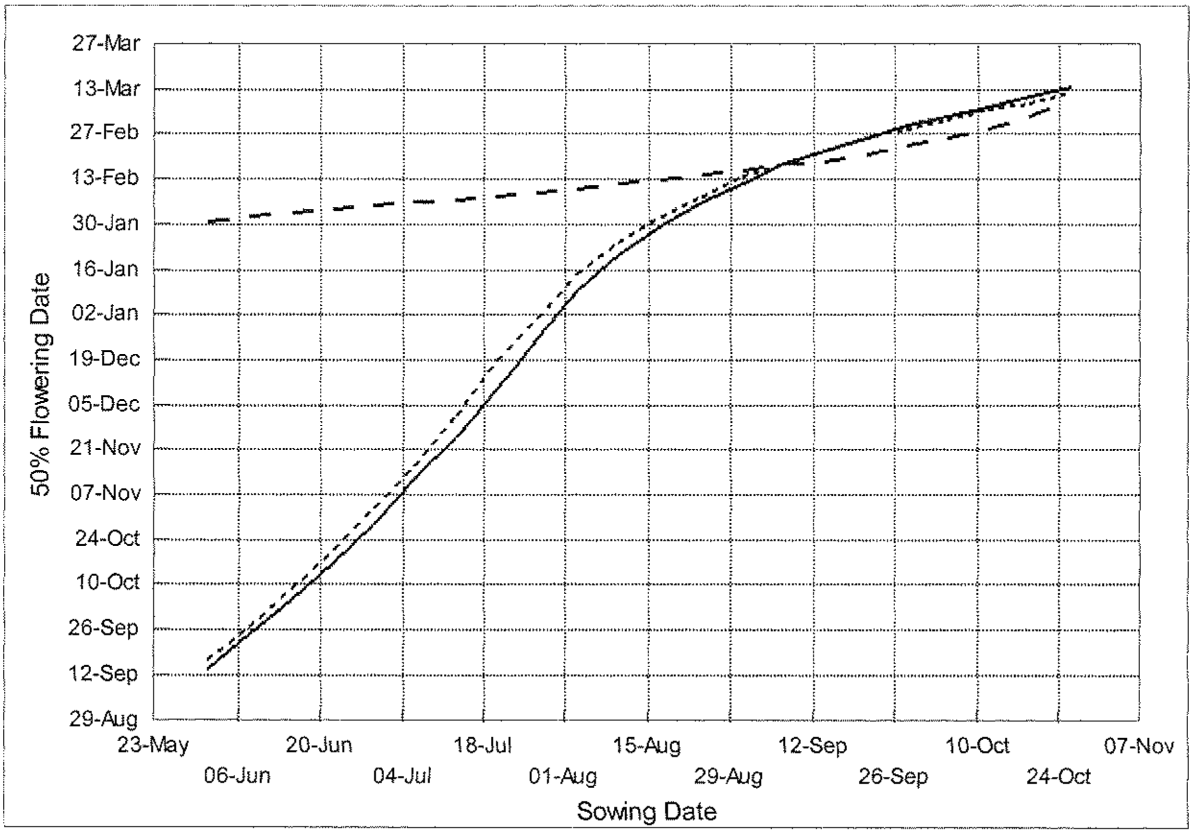
An experimental flowering model was tested under semi-commercial conditions at HRI Efford. Four batches of each of the three varieties were grown, with sowings on week numbers 33, 37, 41 and 45. Seeds were germinated at WJ Findons and Sons and initially sent to Reading where young seedlings were exposed to three temperature treatments (10, 14 or 18°C). These treatments simulated the effects of warm or cool temperatures on flower initiation, since we knew from earlier studies that small fluctuations in early temperatures may have a substantial effect on flowering. Time to flowering and crop quality was monitored. A variety which is straight forward to schedule should have a relatively stable duration between potting to flowering, irrespective of the sowing date.

The results from these experiments showed large varietal differences in their time to flowering and overall variability. Star Wars showed great differences in time from potting to flowering with sowing date. The earliest batches sown in week 33 took between 17 to 25 weeks to flower, whilst those sown in week 50 required between 6 to 12 weeks. The delayed flowering in Star Wars with the earliest potting is not surprising given its high sensitivity to warmer temperatures which would have occurred during the summer months. Meteor and Venezia were much more stable and for each potting required approximately between 5 to 10 weeks from potting up the plugs. Thus, despite the extremely complicated linkage between flowering and environment, Venezia and to a lesser extent Meteor are extremely well adapted for scheduling.

The experimental flowering model was used to predict when the Efford grown crops would mature, given the prevailing temperature, day length and light conditions. The models performed well and were able to predict 50% maturity date to within +/-5 days.

As an example of the potential value of the experimental model Figure C shows a sowing date schedule for Venezia, Meteor and Star Wars assuming that they are grown in frost protected structures through the year. It was assumed that greenhouse temperatures would be 4 degrees higher than typical ambient, and the crop was produced in the Midlands. From this curve, a grower can select a maturity date and read back when they are required to sow the crop.

Figure C. Sowing date schedules for Venezia (line, ——), Meteor (dotted, …….) and Star Wars (dashes,------). These were produced by the experimental flowering model for cineraria assuming that the crop was produced with frost protection only.



Environment post flower initiation also had a significant effect on final plant quality. The most marked feature was that fresh and dry weight, and partially leaf area, decreased as temperature increased. Thus, boosting temperature to flush a crop rapidly post initiation will have a cost in terms of reductions in quality. Conversely, cineraria can become too vegetative, such that warmer temperatures could be desirable to reduce growth.

The finding that the variability in time to flowering was largely a function of light level during the later stages of development was also important. As far as we are aware this is one of the first solid reports of such a phenomenon occurring in cineraria. Similar effects are known to occur with pot chrysanthemum where supplementary lighting during the later stages of development reduces crop variability, in terms of the spread of flowering dates within a crop. Such information will be increasingly important in the future, since if a crop can be flowered uniformly, as a batch, then valuable glasshouse space will be released rapidly to increase subsequent throughput. Labour costs for picking over a crop maturing over a prolonged duration would also be reduced.

SCIENCE SECTION

LITERATURE REVIEW AND BACKGROUND

Cineraria (*SenecioH hybridus* Hyl.) are a popular pot plant crop grown overwinter in a diverse range of structures, from frost protected polytunnels to heated glass. There has recently been renewed commercial interest in this crop, since multiples view it as an attractive alternative winter / spring flowering crop to main stream items such as pansy and primrose. However, traditional cineraria cultivars have been notoriously difficult to schedule and programme. This has prevented retailers stocking the succession of crops required to build up demand. However, recent breeding has led to the development of the Venezia range of colours, which are reputed to flower reliably and consistently between potting of successive batches. This claim has not been tested. There is also considerable interest in developing improved production schedules for other commercially important cultivars.

In order to develop effective and reliable plant scheduling strategies, a full understanding is required of the environmental factors governing the progress to flowering. Flowering in cineraria has been subject to an unusual amount of prior investigation for a pot plant crop. However, the effects of the environment on flowering in cineraria have yet to be fully resolved to the point at which schedules can be developed.

The earliest work on cineraria was reported by Post (1942) who showed that time to flowering was reduced when plants were exposed to a period of cool temperatures during early development. Hildrum (1969, 1971) subsequently confirmed these earlier findings and showed that the development of the flower was stimulated when long days were given after a cold treatment, but had no effect when applied during the treatments. Subsequent to Hildrum's work, an extensive study of the factors affecting flowering in cineraria was conducted by Rolf Larsen, at the Swedish University of Agricultural Sciences, Alnarp (Larsen, 1988a and 1988b). From his work he developed a model to predict the time to flowering in cineraria in response to temperature, photoperiod and light integral.

The model was developed for an old cultivar 'Moll's Stam' from extensive temperature x sowing date experiments, i.e. cineraria were grown in batches at two weekly intervals throughout the year and on each occasion at one of four temperatures between 15 and 24°C. The model split the time to flowering into four key phases, each occurring subsequent to each other; germination, leaf formation, vernalisation and flower development. Rate of progress to seed germination was assumed to be dependent solely upon temperature. Thereafter, Larsen assumed that leaf development was related to temperature and light integral. When the plant had initiated 6 leaves, it was assumed to be ready for vernalisation; i.e. could respond to a cold stimulus for flowering. The duration of the vernalisation phase was determined by a complicated function that considered the combined effects of temperature and photoperiod. The model predicted that the most effective vernalisation temperatures would be between 5 to 9°C, with no initiation occurring when temperatures exceed 14°C. The model also assumed that cineraria were a qualitative short day plant for initiation, i.e. flower initiation was advanced considerably by short days lower than 12 hd^{-1} and completely prevented when day length was longer than 12 hd^{-1}. The duration of vernalisation required was in the order of 4 weeks when temperature and photoperiod were optimal.

Following a successful vernalisation phase, i.e. the flower had been induced, the model then predicted the duration of flower development (which ended on the first flower opening) as a function of temperature, light integral and photoperiod. Very low light integrals (<2 MJ m^{-2} d^{-1}; total solar radiation equivalent to a February day) were assumed to delay flower opening. In terms of the photoperiod response, Larsen assumed that flower development was advanced by long days (the reverse of the day length response used to predict the vernalisation phase). The model assumed the critical day length was 13 hours per day, i.e. flowering was advanced if the photoperiod was greater than that value. For example, at 18°C the model predicted flower development to be 40 days at a day length of 17hd^{-1} compared to 46 days at 14hd^{-1}. Warmer temperatures advanced flower development, for example the model predicted at a daylength of 14hd^{-1} flowers would open after 82 days at a mean temperature of 12°C compared to 38 days at 22°C. The Larsen model has not, however, been validated on any UK grown cineraria, or more modern cultivars.

The most recent study of flowering in cineraria has been conducted in a PhD study at the University of Nottingham, see Yeh and Atherton (1997a and 1997b) and Yeh, Atherton and Craigon. These studied flowering in the Cindy series of cineraria. These workers confirmed in greater detail Larsen's assumption that flower initiation in cineraria was advanced by short days. They also confirmed his assumption that cineraria have a juvenile phase of 6 to 7 leaves prior to them becoming sensitive to cool temperatures. They also presented a model to predict the leaf number below the flower given any temperature (Yeh, Atherton and Craigon, 1997), but not time to flower initiation.

To date, however, there have been no attempts to apply any of this information to the commercial production of cineraria in the UK, or any work on the varieties currently in production.

OBJECTIVES

- Investigate how the environmental factors, temperature, light integral and photoperiod, affect flower initiation and time to flowering in cineraria. The effect of these factors on final plant quality was also studied.

- Investigate whether or not the variety Venezia requires cool temperatures for flowering and therefore whether or not it can be more reliably scheduled.

- Investigate the effects of environment on variability in time to flowering in Cineraria.

- Use the information to develop a scheduling and forecasting programme for commercial Cineraria crops.

- Validate the schedules using Cineraria grown under semi-commercial conditions.

MATERIAL AND METHODS

The work program was divided into two phases. The first, conducted at Reading, involved detailed experiments to quantity the effects of environment on the growth and development of cineraria. These studies involved detailed investigations of the effects of temperature and photoperiod on time to flower initiation and flower development. This data were subsequently used to develop an experimental scheduling model for cineraria. The second phase of work at HRI Efford involved model validation with crops grown under semi-commercial conditions. It also involved a comparison of main stream cineraria cultivars.

Experiment 1. Flower Initiation

In order to establish the time of flower initiation and leaf production rate two varieties (Starwars and Venezia) were grown in a combination of six set temperatures (between 6 to 26°C) and four photoperiods (8, 11, 14 and $17hd^{-1}$) and dissected at three to seven day intervals throughout their growth. Seed were not available to study the responses of Meteor, though similar experiments had been conducted at Reading with Meteor in the previous year.

Plants were placed in one of six identical (3 x 7.2m) controlled temperature glasshouse compartments with heating set point temperatures of 6, 10, 14, 18, 22 and 26°C; mean actual temperatures over the first five weeks of the experiment were 9.8, 13.1, 16.8, 20.7, 23.6 and 27.1°C, respectively. Ventilation set point temperatures were 4°C higher than the respective heating set points. Each compartment contained a suite of four light tight photoperiod control chambers. Plants remained inside the greenhouse compartments from 08:00h to 16:00h each day. At 16:00h each day, plants were wheeled into the photoperiod chambers, where the photoperiods were extended for the desired period at a photon flux density of $11\mu molm^{-2}s^{-1}$ provided by a 40W tungsten and a 15W compact fluorescent lamp. The photoperiod treatments imposed were 8, 11, 14 and $17hd^{-1}$. All chambers were continuously ventilated with a 40W fan.

Seed were sown on 29/9/97 and germinated in a controlled environment room set at 20°C for 3 weeks. Seed were sown in P84 plug trays containing a peat-based seed and modular compost (SHL, William Sinclair Horticulture Ltd, Lincoln, UK) mix. After germination, plug trays were transferred to the factorial temperature and photoperiod controlled greenhouses. There were 65 plants per variety per treatment. 54 days after the start of the experiment (29/10/97), all plants were potted up into 9cm pots containing a peat-based compost. Throughout the experiment, plants were irrigated with a nutrient solution (Sangral 1:1:1 liquid feed) diluted to a conductivity of 1500mS to give (182 $mg.L^{-1}$ N: 78$mg.L^{-1}$ P_2O_5: 150 mg L^{-1} K_2O), and acidified to a pH of 5.8 with nitric/phosphoric acid.

Every 3 to 7 days, three plants from each treatment and variety combination were randomly sampled and dissected under a microscope. Apical diameters were measured using a calibrated graticule and leaf number below the apex determined.

Experiment 2. Effects of temperature and photo-period on flower development

A second experiment was conducted to assess the effects of temperature and photoperiod on flower development post initiation. Initiated plants grown in experiment 1 were potted on and grown in a factorial combination of six temperatures and 4 photoperiod, as above. Time to flowering was recorded for each replicate plant (approx. 5 plants per treatment). Replicate number was not as large as anticipated as time to flower initiation took longer than expected, i.e. many plants had to be dissected prior to the start of experiment 2. At flowering each individual plant was dissected to determine fresh weight, leaf area, plant height, leaf number and dry weight.

Model Development

Data from these two experiments were used to calibrate a series of experimental models to predict time to initiation and subsequent flowering in cineraria. Data from extensive previous studies at Reading were also used in model calibration. This included experiments on the effects of temperature and photoperiod on time to flower initiation of cultivar Meteor and experiments on the effects of environment on flower development in Meteor. A further validation set (from HRI Efford) on the effects of the environment during initiation on subsequent flowering, variability and plant quality was also used.

Plant material:

Three varieties of cineraria were used:

(i) 'Starwars'

(ii) 'Meteor' (seed colour mix)

(iii) 'Venezia' (seed colour mix supplied by Sluis and Groot).

- The efforts of Sluis and Groot and Samuel Yates Seeds in supplying seed when in short supply are gratefully acknowledged.

Cultural techniques:

Propagation:

Commencing week 27, seed were sown into P360 trays according to standard commercial practice by WJ Findons Ltd. Using a low nutrient seedling media (8mm grading) with a light covering of coarse grade vermiculite. Seed were germinated at 18-20°C for 4-5 days and then moved to the glasshouse under fog at 16-18°C. Seedlings were kept in the glasshouse under these conditions for 7 days before being transferred into an un-fogged glasshouse at 14-16°C. Overhead shade was set to 200 Wm^{-2} rising to 300 Wm^{-2}. 21 days after sowing, seedlings were transported to The University of Reading for initiation treatments, and plants were transferred to 63 cell plug trays.

- Seedlings were produced for treatments at four potting dates in weeks 33, 37, 41 and 45*.

The three initiation temperature treatments were applied under natural day-length conditions for 3 weeks in the University of Reading's temperature-controlled suite of glasshouse compartments, these were;

o 14°C (Control)

o 10°C (Cool)

o 18°C (Warm)

* Seed material for Meteor was not available for the week 45 potting and in this instance Meteor

was substituted with 'Brilliant'. Potting 4 was complemented by a 5th potting in week 50.

Schedule:

After temperature treatments were completed at Reading, treated plants were transported to HRI Efford . Seedlings were potted into 13cm pots using Levington C2 compost. Plants were introduced into a common environment in P block with pot spacing = 12 m^{-2} (28.9 cm pot centre - pot centre in staggered arrangement with row-row spacing = 25 cm).

Environment/Nutrition:

Light: From August (week 33) to the end of September (week 40), plants were grown with permanent overhead shading provided by a single layer of Rokolene. In addition, during the early stages of production when light levels were high, benches were individually shaded with extra Rokolene to avoid leaf scorch and excessive diurnal wilting. The extra shading was removed as soon as ambient conditions permitted. Solarimeters on each bench measured light continuously throughout the trial and enabled us to take account of the variability in light environment from bench-to-bench. For details of temperature treatments in the University of Reading and HRI Efford see Appendix 2.

Temperature

The glasshouse environment was kept as cool as prevailing conditions allowed by active venting during the day. Temperature set points were 10/11°C day/night with venting at 12°C. In the early pottings, when external light level and temperatures were very high, additional screening (Rokolene) was used over individual benches as required to protect young plants from scorch. The Rokolene screens were only used as necessary before the plants could be weaned into the prevailing glasshouse environment (when individual benches were screened, solarimeters on the bench under the screening took account of the effects of screening for modeling purposes).

Irrigation

Plants were cultured as dry as possible to control growth and avoid soft, leafy development. Care was taken to avoid leaf scorch (shading in addition to permanent overhead screen was applied as required).

Nutrition Until Potting

Once cotyledons had expanded, weekly feed incorporating 50ppm N increasing to 75ppm was applied. From first true leaf, 100ppm N from a 20:10:20 N:P:K fertiliser. Media was not allowed to dry out.

After Potting

Liquid feed started when roots reached the edge of the pot, when feed containing 150 ppm N : 200 ppm K_2O was applied with every irrigation.

Pest and Disease Control

After transferred to 63 cell plug trays, plants were drenched with Furalaxyl (Fongarid 25 WP, 25mg/l, Ciba-Geigy Agrochemicals, Whittlesford) immediately and every two weeks thereafter. For thrips, teflubenzuron (Nemolt, 0.5ml/l, Fargro, Littlehampton) was sprayed every two weeks.

IPM was used as far as possible, with Amblyseius CRS sachets introduced every 8 weeks against Thrips; Hypoaspis against Sciarid fly larvae. Chemical applications were occasionally used to control aphid, Tiralic and rust. Agents against rust were tested on a few guard plants: Plantvax (0.5 g/l + Agral 0.1 ml/l); Tilt (2.5 ml/l) & Dorado (0.25 ml/l). None of the chemicals tested (at the rates used) resulted in phyto-toxicity under the prevailing conditions.

Plant Growth Regulation

Plant growth was controlled by growing pots as dry as possible without letting them dry out too much, with every precaution taken to avoid scorch.

Summary of the experimental design: HRI Efford

12 benches, each holding 3 plots with plot size = 32. Plants arranged 4 across a bench at a final pot spacing of 12 /m^2.

3 Initiation temperature pre-treatments
x
4 potting dates
x
3 varieties
--
36 Total plot number

Plots were blocked by potting date, with a single variety per bench. This design enables the main comparison between treatments within a variety and potting date

Experimental records: HRI Efford; Growing-on phase

18 plants per plot were recorded (+ 6 guards as a separate record to study edge effects).

Records at potting:

- Plant height (cm): measured from compost surface to crown
- Plant spread (cm): across widest point and at right angles

Records during plant development:

- Time to first 5mm diameter bud (recorded pot by pot)

At flowering:

- Time to first flower opening (and number of flowers on that plant if more than one open flower at first record; recorded pot by pot)
- At 2 - 3 day intervals after first flower opening until 14 days after first flower (pot-by-pot).

To investigate the rate of and variability in flower opening under different conditions.

- Number of open flowers
- Time to marketing (5-8 flowers open) determined from the above records

14 days after first open flower:

1 - a) Corim score: Score 1 = Good discrete 2-tier dome with flowers above canopy
Score 2 = Flat dome
Score 3 = Uneven dome with irregular spikiness
2 - b) Flower evenness Score 1 = Uniform flower cover
Score 2 = Small patches around corim
Score 3 = Unsymmetrical and patchy flowering
3 - c) Foliage score Score 1 = Green, compact, uniform foliage under flowers
Score 2 = Yellowing foliage, irregular distribution under flowers
Score 3 = Foliage uneven and protruding through flowers
4 - Photographic records taken for initiation treatment comparisons and as score standards.
5 - Plant height (cm)
6 - Plant spread (cm)

In addition, 5 plants were selected at random from each plot (14 days after first flower) for destructive measurements of:

- Leaf number per plant
- Leaf area per plant (excluding petioles)
- Leaf dry weight per plant in grams (excluding petioles)
- Flower number per plant
- Flower dry weight per plant in grams (excluding pedicels)
- Above ground dry weight of remainder of plant in grams (stems, pedicels and petioles)
- General comments of plant health (from destructive samples only).

RESULTS

Effects of Temperature and Photoperiod on Flower Initiation

The effect of temperature and photoperiod on flower bud initiation were investigated by dissecting plants at regular intervals throughout development. This generated a considerable data set. Figure 1 shows the relationship between apical diameter and time from sowing for Venezia grown at 9.4 and 16.7 °C. These data illustrate the generality of the responses, data from other cultivars and environmental treatments are summarized later.

The apices became reproductive when they attained a diameter of 0.25mm. Figure 1 shows that temperature and photoperiod had a considerable affect on apical development. For instance, at an 8 hour photoperiod, the number of days required to reach an apical diameter of 0.25mm was 69 at 9.4°C and 98 at 16.7°C.

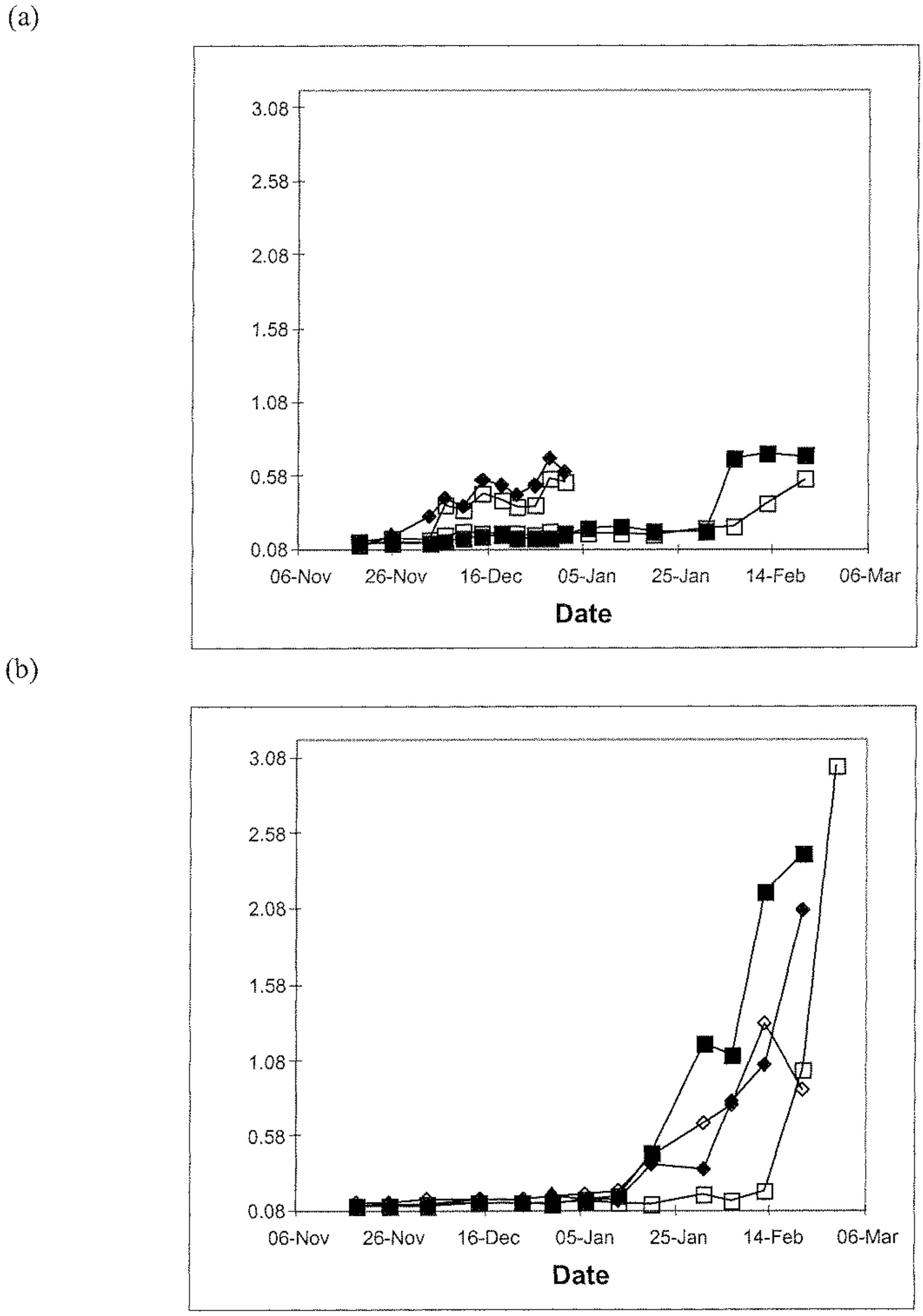


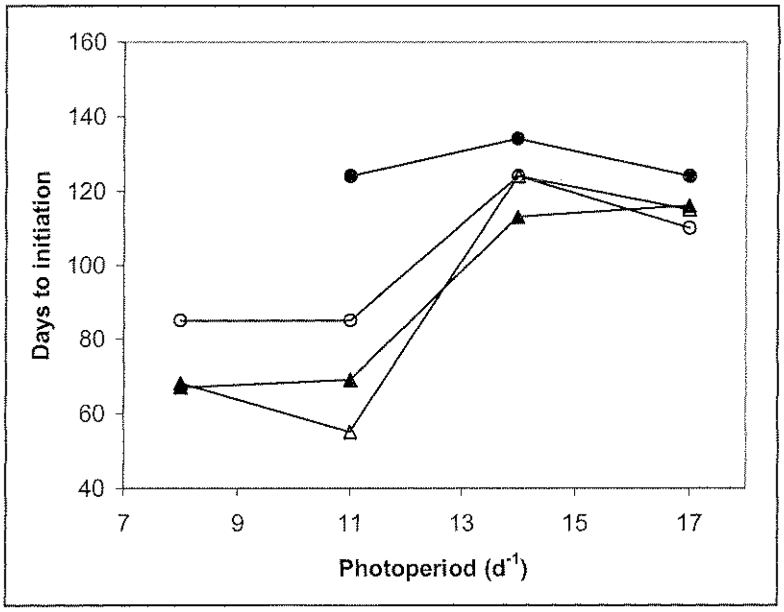
Figure 1 a and b. The increase in apical diameter of Venezia grown at either 9.4 (1a) or 16.7°C (1b) and one of four photoperiods (♦ 8, ◇ 11, ■ 14, 17hd^{-1}).

For the data from all cultivars and environmental combinations, linear interpolation was used to determine the time when the flowers became reproductive. This was considered as the point when the rate of apical expansion dramatically increased. This rapid expansion occurred once the apical diameter had reached 0.25mm.

Figure 2a and 2b shows for Venezia and Star Wars the relationship between time to flower initiation and temperature and photoperiod. The time to flower initiation was highly dependent upon both day length and temperature, with time to initiation varying between 66 to 138 days depending upon treatment. Under short days (8 to 11h d^{-1}) time to flower initiation was most rapid at the coolest temperature (9.4°C). Warmer temperatures led to a delay in flower initiation, and the sensitivity to temperature was considerable, plants at 11 hd^{-1} at 20.3°C took twice as long to initiate flowers as those at 9.4°C. Under long days, time to flower initiation was less dependent upon temperature, but earliest flower initiation occurred at intermediate temperatures (12.7 to 16.7°C). The main differences between the varieties was that Star Wars was much less sensitive to short days for flower initiation. Thus, at approximately 9°C Venezia required 66 days to initiate at $11hd^{-1}$ and 118 at $17hd^{-1}$ whilst Star Wars required 110 and 127 days, respectively. In terms of the temperature response, Star Wars did not initiate any flowers when temperatures exceeded 17°C (when photo period also had no affect), and then they were very late (152 days, compared to 125 with Venezia). Venezia initiated even at 20°C.

This suggests that the large response to short days and rapid flowering at warmer temperatures in Venezia will make the variety capable of flowering during both the summer and winter months.

(a)



(b)

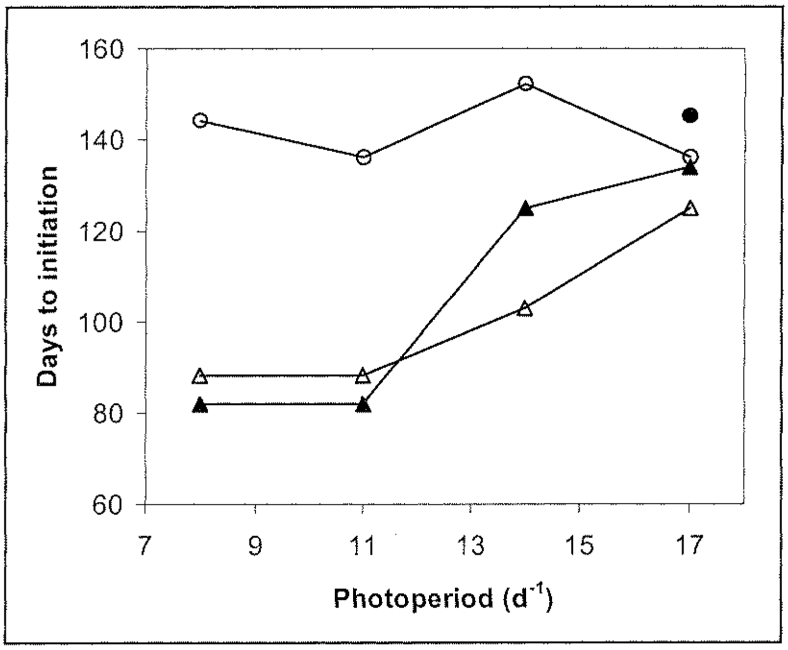


Figure 2a and b. The effects of photo-period and temperature (● 20.3°C; ○ 16.7°C; ▲ 12.7°C; △ 9.4°C) on time to flower initiation in Venzia (2a) and Star Wars (2b).

Flower Development

A second experiment examined how environment following flower initiation affected the rate at which flowers develop. In this instance, the response to environment completely changed, (see Figure 3a, 3b, 3c). Short days tended to delay time to flowering (from initiation to opening), such that Venezia grown at 8h d^{-1} and the warmest temperature flowered 10 days later than those at $17hd^{-1}$. The short day delay was more marked with Star Wars and Meteor, where the comparable delay was 40 days at the shortest compared to longest photoperiod. Warm temperatures promoted flower development, for example with Venezia plants at 9.5°C flowering on average 30 days later than those at 20°C. These data on flower initiation and development demonstrate the highly complex linkage between environment and time to flowering in cineraria.

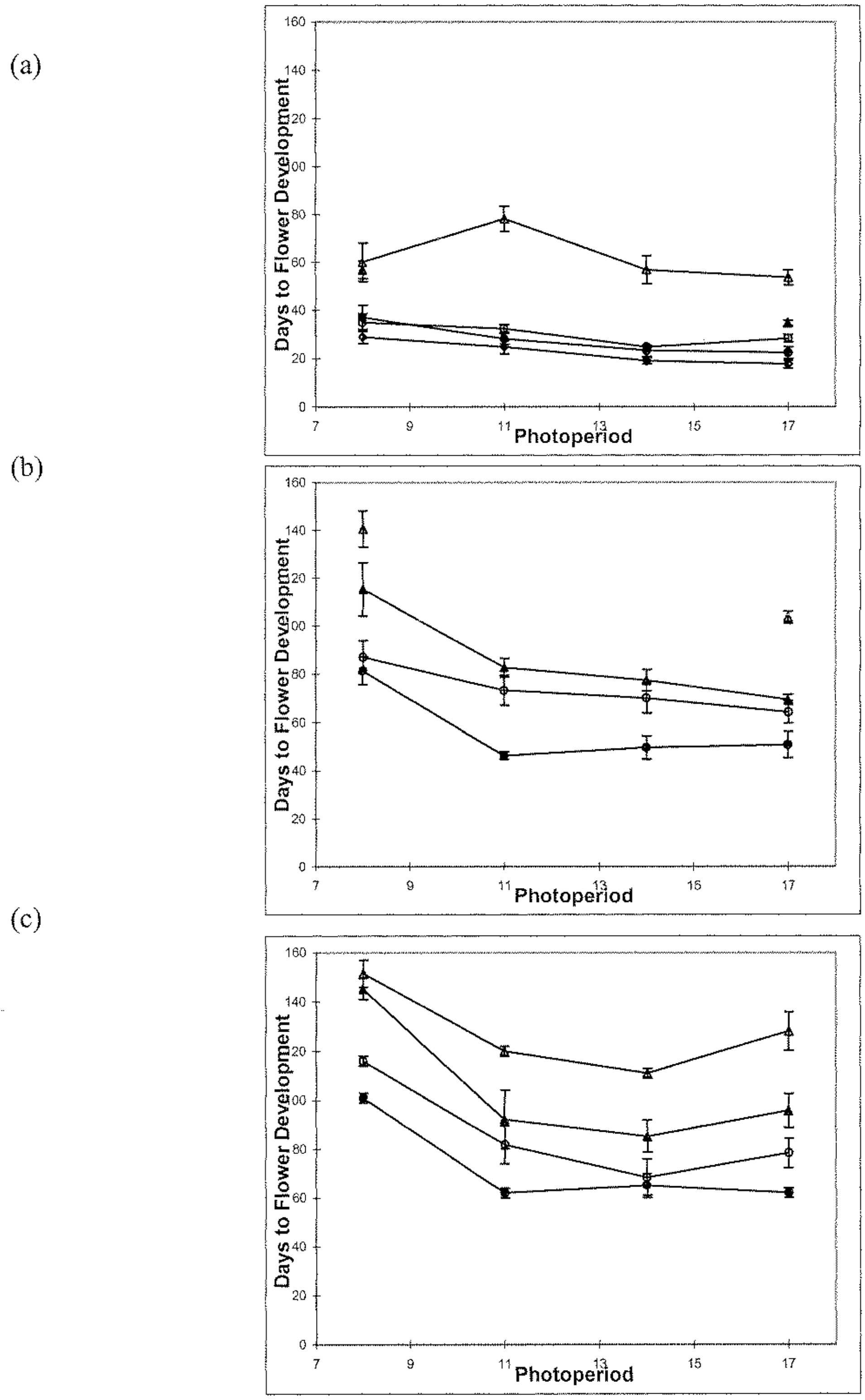


Figure 3. Effects of photoperiod and temperature (◆ 23.8°C; ● 20.8°C; ○ 16.9°C; ▲13.1°C; △ 9.6°C)) on duration of flower development in cv. Venezia (3a), Meteor (3b) and Star Wars (3c).

Variability in time to flowering

One of the objectives of this study was to demonstrate which environmental factors give rise to variability in the final spread of flowering in cineraria. This is commercially important as it would be advantageous to rapidly clear out a crop, compared to one picked over for many weeks. Figures 4a, b and c show the duration of the flowering period for each of the crops grown at Reading. Although there was considerable spread in the variability in time to flowering for all three varieties, growing the plants in short photoperiods tended to increase the duration over which a crop flowered. Temperature had less effect, the most notable exception was for the cv. Venezia, where growing the plants at a temperature of 9.6°C tended to increase the time from first to last flowering.

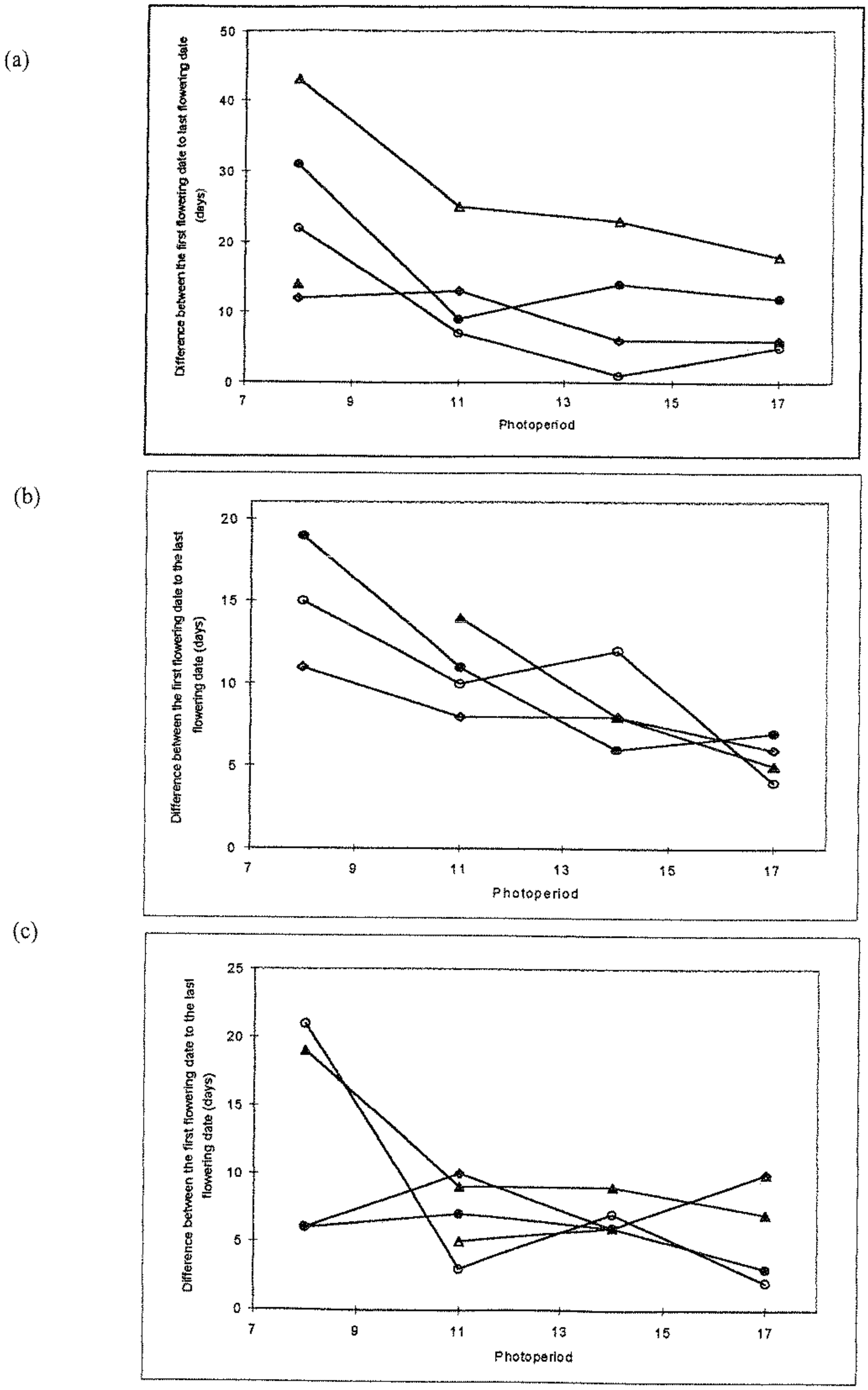


Figure 4. Effects of photoperiod and temperature (◊ 23.8°C; • 20.3°C; ○ 16.7°C; ▲ 12.7°C; △ 9.4°C) on variability of flowering in cv. Venezia (4a), Meteor (4b) and Star Wars (4c).

Tables 1 to 3 show the effects of the environment during flower development on final quality, measured in terms of fresh and dry mass, height, node number and leaf area at first flowering.

Table 1. The effect of temperature and photoperiod on plants fresh and dry mass, leaf number, stem length number of nodes and leaf area in cineraria (*Senecio hybridus*) cv. Venezia.

Temp (°C)	Photo (hd^{-1})	Fresh mass (g)	Leaf Number	Plant ht (cm)	Node No[y]	Leaf area (mm^2)	Dry mass (g)
9.8	8	67.9	21.8	9.14	23.4	4783	5.71
9.8	11	70.8	24.2	10.8	25.8	4352	5.72
9.8	14	65.1	23.2	10.1	25.4	4519	5.6
9.8	17	71.5	26.2	10.3	28.8	4976	5.79
13.2	8	52.9	25	9.1	28	4614	4.27
13.2	17	47.7	27	13.2	30	5081	3.79
17.1	8	54.8	26.5	9.63	28	4379	3.76
17.1	11	61.5	23	10.35	24.8	5035	4.4
17.1	14	46.7	26	11.8	28	4277	3.19
17.1	17	42.1	21.2	10.4	24.8	3874	2.91
20.9	8	44.3	23.8	8	26.5	4046	2.84
20.9	11	30.6	22.5	9.13	23.8	3901	3
20.9	14	33.6	24.8	9.38	27.2	3638	2.34
20.9	17	34	23.6	9.9	25.4	3774	2.5
24	8	36.4	28.8	7.08	23.8	3949	2.32
24	11	29.8	23.5	7	25	3301	2.18
24	14	26.9	23.6	8.4	24.8	2896	2.02
24	17	27.1	25.4	8.38	27	3063	2.05
P^t		***	NS	***	*	***	***
P^p		*	NS	***	NS	NS	NS
P^i		NS	NS	NS	*	NS	NS
SED^t		5.95	0.31	0.4	0.45	24.3	0.52
SED^p		1.4	0.22	0.31	0.31	13.3	0.1
SED^i		3.7	1.65	1.41	0.47	56.74	0.21

Means of from 5 replicate plants

[y] Below the flower

P^t, p^p, P^i correspond to significant with temperature, photoperiod and interaction, respectively.

NS, *, *** Nonsignificant or significant at $P<0.05$ or 0.001, respectively.

SED^t, SED^p and SED^i correspond to temperature, photoperiod and the interaction, respectively.

Table 2. The effect of temperature and photoperiod on plants fresh and dry mass, leaf number, stem length branch number, number of nodes and leaf area in cineraria (*Senecio hybridus)* cv. Meteor.

Temp (°C)	Photo (hd^{-1})	Fresh mass (g)	Leaf Number	Plant ht (cm)	Branch No	Node No^{y}	Leaf area (cm^2)	Dry mass (g)
9.7	8	132.16	21	12	15	22.5	7026.5	5.23
9.7	17	77.89	23.5	15.98	14.5	25.5	10237.5	6.05
11.5	8	62.4	20.5	11.9	14	22.5	6009.4	3.93
11.5	11	57.69	19	9.4	12.8	21.2	6142.2	4.1
11.5	14	50.09	21.8	10.98	15.8	23.8	6263.6	3.84
11.5	17	44.63	25.8	10.3	13	27.8	6280.2	3.56
17.2	8	48.2	23.35	9.13	13.5	25	5330.2	2.9
17.2	11	27.64	25.5	9.33	12	27.3	4106.5	2.24
17.2	14	31.81	23.5	9.96	13.75	25.25	4938	2.36
17.2	17	32.09	26.75	10.7	10	27.5	4557.5	2.39
20.4	8	41.66	25.4	11.34	15.4	29.4	5435.4	2.86
20.4	11	32.24	23.5	7.23	12.25	23.75	3657	2.04
20.4	14	22.97	22.5	7.7	12.25	23	3389	1.67
20.4	17	23.61	27	8.03	12.25	27.75	3562.75	2.06
P^t		***	NS	NS	***	NS	***	***
p^p		***	*	*	NS	*	NS	NS
P^i		NS	NS	NS	*	NS	*	*
SED^t		8.56	0.59	0.35	0.74	0.44	30.10	0.44
SED^p		4.01	0.69	0.43	0.29	0.68	31.93	0.08
SED^i		5.41	1.08	0.78	1.13	1.65	30.54	0.51

Means of from 5 replicate plants

[y] Below the flower

P^t, p^p, P^i correspond to significant with temperature, photoperiod and interaction, respectively.

NS, *, *** Nonsignificant or significant at $P<0.05$ or 0.001, respectively.

SED^t, SED^p and SED ^{i}correspond to main effects of temperature, photoperiod and interactions, respectively.

Table 3. The effect of temperature and photoperiod on plants fresh and dry mass, leaf number, stem length branch number, number of node and leaf area in Cineraria (*Senecio hybridus)* cv. Star Wars.

Temp	Photo	Fresh mass (g)	Leaf Number	Plant ht (cm)	Branch No	Node No[y]	Leaf area (cm^2)	Dry mass (g)
10.01	8	30.2	22.5	10.7	13.5	25.0	2294.5	2.35
10.01	11	136.6	22.0	10.7	13.0	23	8176.5	8.51
10.01	14	99.0	35	17.4	21.0	36	10277.0	8.51
10.01	17	74.8	34.0	17.4	17.3	36.7	7317.7	7.15
11.8	8	38.1	28.4	10.9	11.8	31.8	3993.2	3.05
11.8	11	57.1	28.4	9.8	16.2	29.0	6496.4	3.98
11.8	14	74.5	30.3	12.7	16.5	32.3	7655.5	5.57
11.8	17	55.7	29.0	17.4	18.0	31.5	7445.3	4.51
16.8	8	35.3	33.3	10.4	17.3	36.8	2919.0	3.04
16.8	11	49.6	28.4	9.9	14.8	31.4	4115.7	3.61
16.8	14	51.9	23.1	10.4	12.4	29.8	7171.2	4.75
16.8	17	48.9	30.6	12.8	13.2	31.6	7500.5	3.67
20.1	8	40.8	25.0	10.7	14.0	29.0	3592.0	3.26
20.1	11	38.87	24.0	8.3	11.0	26.0	2412.0	2.74
20.1	14	27.7	26.0	8.4	13.0	28.5	3149.0	1.84
20.1	17	34.7	23.0	8.6	13.0	25.0	5701	2.49
P^t		***	NS	*	NS	NS	NS	*
p^p		***	NS	***	NS	NS	***	*
P^i		*	NS	NS	*	NS	NS	NS
SED^t		6.58	0.09	0.63	0.39	0.28	12.01	0.46
SED^p		5.29	0.55	0.83	0.26	0.60	30.91	0.36
SED^i		12.50	3.25	1.15	2.16	2.84	37.60	0.75

Means of from 5 replicate plants

[y] Below the flower

P^t, p^p, P^i correspond to significant with temperature, photoperiod and interaction, respectively.

NS, *, *** Nonsignificant or significant at $P<0.05$ or 0.001, respectively.

These indicate final plant quality at first flowering was strongly affected by temperature and photoperiod, post initiation. Temperature and photoperiod significantly affected fresh weight at harvest in all three varieties. For all three varieties, increasing temperature from approximately 10 to 20°C halved plant fresh weight, similar responses were noted with plant dry mass. Photo period effects were less clear, with Venezia and Meteor short days led to increased plant weight, but the reverse occurred with Star Wars. Across all three varieties, photoperiod significantly affected plant height, however, absolute differences were small, with plants being approximately 1cm taller under the long compared to short day treatments.

Model Development

The data on flower initiation and flower development shown above were used to construct an experimental scheduling model. This experimental model was subsequently tested under semi-commercial conditions at HRI Efford. Four batches of each of the three varieties were grown, with sowings on week numbers 33, 37, 41 and 45. Seeds were germinated Sons and initially sent to Reading where three temperature treatments were imposed for three weeks onto the young seedlings; 10 14 or 18°C. These treatments were to simulate the effects of warm or cool temperatures on flower initiation, since we knew from earlier studies that small fluctuations in early temperatures may have a substantial effect on flowering. Times to flowering and crop qualities were monitored.

It is worth re-iterating here that a variety which is straight forward to schedule should have a relatively stable duration between potting to flowering, irrespective of the sowing date.

Large varietal differences were noted in the time period to flowering. Star Wars showed the greatest variation in time from sowing/potting to flowering. The earliest batches sown in week 33 took between 17 to 25 weeks to flower, whilst those sown in week 50 required between 6 to 12 weeks. The delayed flowering in Star Wars with the earliest potting was not surprising given its high sensitivity to warmer temperatures which would have occurred during the summer months. Meteor and Venezia were much more stable and for each potting required approximately between 5 to 10 weeks from potting up the plugs. Thus, despite the extremely complicated linkage between flowering and environment, Venezia and to a lesser extent Meteor are extremely well adapted for scheduling.*Plant quality for each sowing date and variety*

Table 4, 5 and 6 show the effects of sowing date on final plant quality for each of the three varieties. These data are also summarized graphically in Appendix 1.

Table 4. The effect of temperature and photoperiod on plants fresh and dry mass, leaf number, stem length branch number, number of node and leaf area in cineraria (*Senecio hybridus*) cv. Venezia.

Sowing	Temp	Flower number	Leaf area (cm^2)	Leaf dry wt/plant (g)	Flower dry wt/Plant (g)	Remainder of plant dry mass (g)
First	A	32.20	1651.8	3.02	0.81	4.99
First	A+4	42.4	1682.0	2.77	0.87	4.30
First	A-4	44.2	1705.2	3.47	0.97	4.07
Second	A	33.6	1476.6	3.18	1.34	5.55
Second	A+4	35.2	1591.8	3.62	0.95	4.25
Second	A-4	37.25	1286.8	2.35	0.82	4.92
Third	A	45.8	1256.8	2.28	1.54	3.53
Third	A+4	41.8	1388.0	2.34	2.03	3.92
Third	A-4	25.8	1136.0	2.12	0.76	2.75
Fifth	A	57.4	1187.0	2.57	2.71	2.83
Fifth	A+4	60.0	1144.0	2.55	2.71	2.84
Fifth	A-4	57.4	1025.4	2.49	2.82	2.37
P^s		*	***	*	*	*
P^t		NS	NS	NS	NS	NS
P^i		NS	NS	NS	NS	NS
SED^t		3.62	89.38	0.15	0.31	0.36
SED^p		0.85	25.06	0.02	0.05	0.11
SED^i		4.05	50.04	0.23	0.22	0.30

Means of from 5 replicate plants

A, A+4, A-4 correspond to Ambient temperature, Ambient temperature+4°C and Ambient temperature-4°C, respectively.

[y] Below the flower

P^s, P^t, P^i correspond to significant with sowing date, temperature and interaction, respectively.

NS, *, *** Nonsignificant or significant at $P<0.05$ or 0.001, respectively.

SED^s, SED^t and SED ^{i}correspond to main effects with sowing date, temperature and interactions, respectively.

Table 5. The effect of sowing date and temperature on plants flower number, leaf area and dry mass of leaf, flower and remainder of plant in cineraria (*Senecio hybridus)* cv. Meteor.

Sowing	Temp	Flower number	Leaf area (cm^2)	Leaf dry wt/plant (g)	Flower dry wt/Plant (g)	Remainder of plant dry mass (g)
First	A	41.4	3130.0	5.07	1.43	8.18
First	A+4	79.0	2375.0	4.7	2.49	6.62
First	A-4	55.4	2293.4	4.09	1.74	5.95
Second	A	51.6	2371.6	4.72	2.61	5.85
Second	A+4	77.8	1827.5	4.06	2.83	6.16
Second	A-4	65.0	2061.8	4.17	1.85	4.03
Third	A	48.2	1972.8	3.46	1.99	4.41
Third	A+4	44.2	1062.4	1.93	1.80	3.06
Third	A-4	48.6	1501.0	2.84	2.37	4.55
Fifth	A	48.0	1074.8	2.51	2.42	3.27
Fifth	A+4	68.6	1131.0	2.74	2.97	3.62
Fifth	A-4	56.4	910.8	2.21	3.04	2.63
P^s		NS	***	***	*	***
P^t		NS	*	NS	NS	NS
P^i		NS	NS	NS	NS	NS
SED^t		2.62	250.15	0.43	0.15	0.60
SED^p		2.65	87.84	0.13	0.05	0.16
SED^i		7.02	149.11	0.31	0.32	0.64

Means of from 5 replicate plants

A, A+4, A-4 correspond to Ambient temperature, Ambient temperature+4°C and Ambient temperature-4°C, respectively.

^{y} Below the flower

P^s, P^t, P^i correspond to significant with sowing date, temperature and interaction, respectively.

NS, *, *** Nonsignificant or significant at $P<0.05$ or 0.001, respectively.

SED^s, SED^t and SED^i correspond to main effects with sowing date, temperature and interactions, respectively.

Table 6. The effect of sowing date and temperature on plants flower number, leaf area and dry mass of leaf, flower and remainder of plant in cineraria (*Senecio hybridus*) cv. Star Wars.

Sowing	Temp	Flower number	Leaf area (cm^2)	Leaf dry wt/plant (g)	Flower dry wt/Plant (g)	Remainder of plant dry mass (g)
First	A	132.4	2780.6	7.45	6.49	14.12
First	A+4	123.2	2781.6	6.12	3.97	13.04
First	A-4	154.4	3001.0	7.52	5.78	13.31
Second	A	144.4	2205.6	5.43	4.71	8.78
Second	A+4	151.6	1958.6	4.47	4.93	7.12
Second	A-4	188.8	2424.0	5.00	6.09	10.16
Third	A	118.6	1588.0	3.59	4.58	5.80
Third	A+4	135.8	1563.0	3.58	4.36	5.36
Third	A-4	120.6	1590.0	3.30	4.30	5.63
Fifth	A	82.2	1232.6	3.52	4.45	4.56
Fifth	A+4	97.2	1037.4	3.16	4.14	3.97
Fifth	A-4	80.4	1094.8	2.79	3.86	4.44
P^s		***	***	***	*	***
P^t		NS	NS	NS	NS	NS
P^i		NS	NS	NS	NS	NS
SED^t		11.4	274.94	0.64	0.22	1.49
SED^p		2.64	30.63	0.11	0.12	0.18
SED^i		9.80	75.80	0.28	0.48	0.45

Means of from 5 replicate plants

A, A+4, A-4 correspond to Ambient temperature, Ambient temperature+4°C and Ambient temperature-4°C, respectively.

^{y} Below the flower

P^s, P^t, P^i correspond to significant with sowing date, temperature and interaction, respectively.

NS, *, *** Nonsignificant or significant at $P<0.05$ or 0.001, respectively.

SED^s, SED^t and SED ^{i}correspond to main effects with sowing date, temperature and interactions, respectively.

Tables 4, 5 and 6 show the effects of the sowing dates, temperature pre-treatments and varieties on a range of plant quality characteristics measured at first flowering. For all varieties and sowing dates, there were strong significant effects of sowing date on all the characteristics measured. Dry mass and leaf area decreased with subsequent sowings. For example, with cv. Meteor the total dry mass at flowering was halved between the first and final potting, leaf area in Venezia was reduced by approx. 40% between the same sowings. Highest plant weights were recorded for the first sowing of Star Wars, though this potting took the longest time to flowering of any treatment.

The main difference between varieties was found in terms of flower number. Star Wars had overall twice as many flowers per plant than Venezia, with Meteor being intermediate. The temperature pre-treatments had little overall impact at final flowering, though plant dry mass tended to be reduced when the plants were exposed to the coldest temperatures during propagation.

Model validation

The experimental flowering model for cineraria was used to predict when the Efford crops would mature, given the prevailing temperature, day length and light conditions. The model performed well and was able to predict 50% maturity date to within +/- 5 days, see Figure 6. This suggests that the model may be used for scheduling, and also for forecasting post sowing, flowering date in cineraria. These errors are relatively small compared to the duration of some of the crops (up to 220 days).

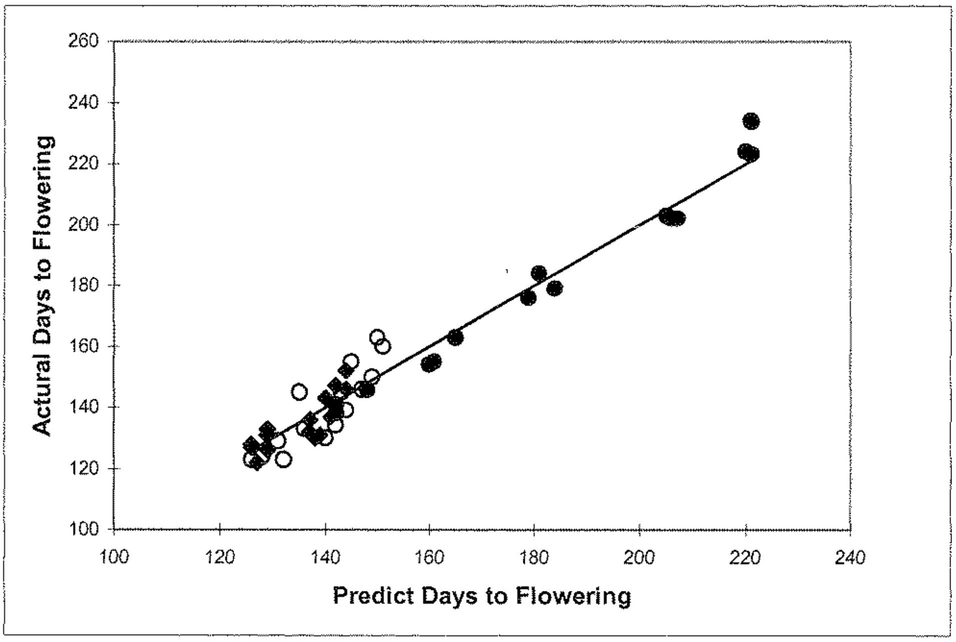


Figure 6. Model prediction versus actual time to flowering of the Efford grown cineraria; ●Star Wars; ○Meteor; ◆Venezia. The solid line is the line of identity.

Scheduling maturity

Figure 7 shows a sowing date schedule for Venezia, Meteor and Star Wars assuming that they are grown in frost protected structures through the year. It was assumed that greenhouse temperatures would be 4 degrees higher than typical ambient, and the crop was produced in the Midlands. From this curve, a grower could select a maturity date and read back when they are required to sow.

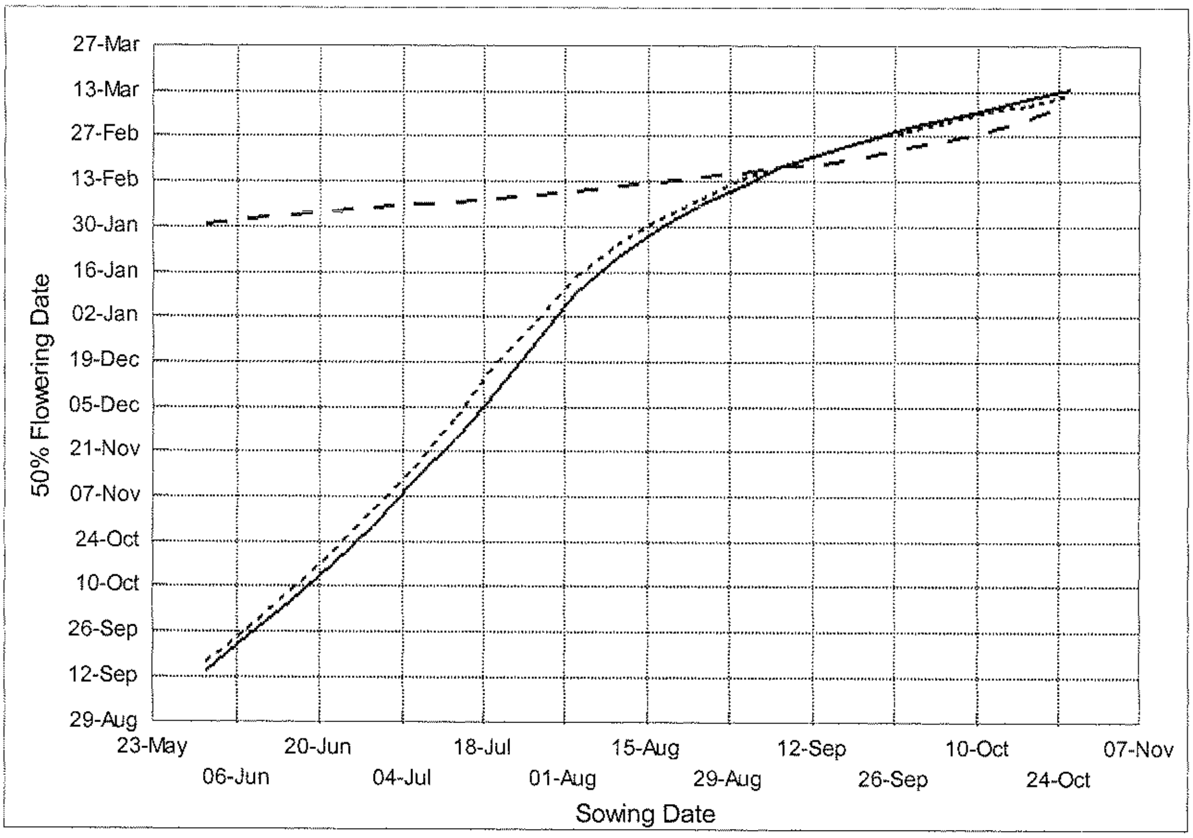


Figure 7. Sowing date schedules for Venezia (line,———), Meteor (dotted,.....) and Star Wars (dashes, — —). These were produced by the model assuming they were produced with only frost protection.

This figure clearly demonstrates the difficulty in scheduling the early production of Star Wars, under frost protection the crop is simulated to first flower at the end of January, despite a June sowing.

CONCLUSIONS

This study has provided an in depth examination of the effects of environment and sowing date on the flowering and quality of cineraria. It has shown flowering in cineraria to be a complex function of temperature and photoperiod, during and after flower initiation. One of the remarkable features of the crop is its response to photoperiod, and how this is dependent upon temperature; during early development flowering is favoured by cool temperatures and short days; at warmer temperatures the effects of short days are less marked. However, following the initiation of the flower its development is favoured by long days and warm temperatures. As such, in terms of crop species, cineraria has one of the most complex linkages between flowering and the environment demonstrated to date. Plants which switch their photoperiod requirement during development are very rare, as are short day plants which require cool temperatures to advance flower initiation. Despite this very complicated linkage with environment Venezia and Meteor were both remarkably well adapted for ease of plant scheduling. Both formed flowers after a fairly stable number of weeks post potting. Plants which are difficult to schedule are those where small changes in environment have a pronounced effect on time to final flowering post potting.

Environment post flower initiation also had a significant effect on final plant quality. The most marked feature was that fresh and dry weight, and partially leaf area, decreased as temperature increased. Thus, boosting temperature to flush a crop rapidly post initiation will have a cost in terms of reductions in quality. Conversely, cineraria can become too vegetative, such that warmer temperatures could be desirable to reduce growth. Plant height increased with photoperiod, however, effects were small and may be attributed to the far red component in the tungsten lamps used to extend photoperiod. Plant size at final flowering also reduced with later sowings. This is not surprising since cineraria sown late mature over the winter when the light available for overall plant growth is limiting.

The finding that the variability in time to flowering was largely a function of light level during the later stages of development was also important. As far as we are aware this is one of the first solid reports of such a phenomenon occurring in cineraria. Similar effects are known to occur with pot chrysanthemum where supplementary lighting during the later stages of development reduces crop variability, in terms of the spread of flowering dates within a crop. Such information will be increasingly important in the future, since if a crop can be flowered uniformly, as a batch, then valuable glasshouse space will be released rapidly to increase subsequent throughput. Labour costs for picking over a crop maturing over a prolonged duration would also be reduced.

ACKNOWLEDGMENTS

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REFERENCES

Hildrum, H. (1969). Factors affecting flowering in *Senecio cruentus* DC. *Acta Hort.* **14,** 117-123.

Hildrum, H. (1971). Modification of flowering in *Senecio cruentus* by means of growth substances. *Proc 18th Int. Hort. Congress*. pp 43.

Larsen, R. (1985). Temperature and flower induction of *Senecio x hybridus* Hyl. *Swedish Journal of Agricultural Research,* **15,** 87-92.

Larsen, R. (1988a). A prediction model for floral development of *Senecio x hybridus* Hyl. >Moll=s Stam=. *Swedish Journal of Agricultural Research,* **18,** 99-103.

Larsen, R. (1988b). A dynamic model for prediction of developmental rate of the pot plant *Senecio x hybridus* Hyl. *Report 53 Swedish University of Agricultural Sciences Alnarp,* 40pp (ISBN 91-576-3446-7).

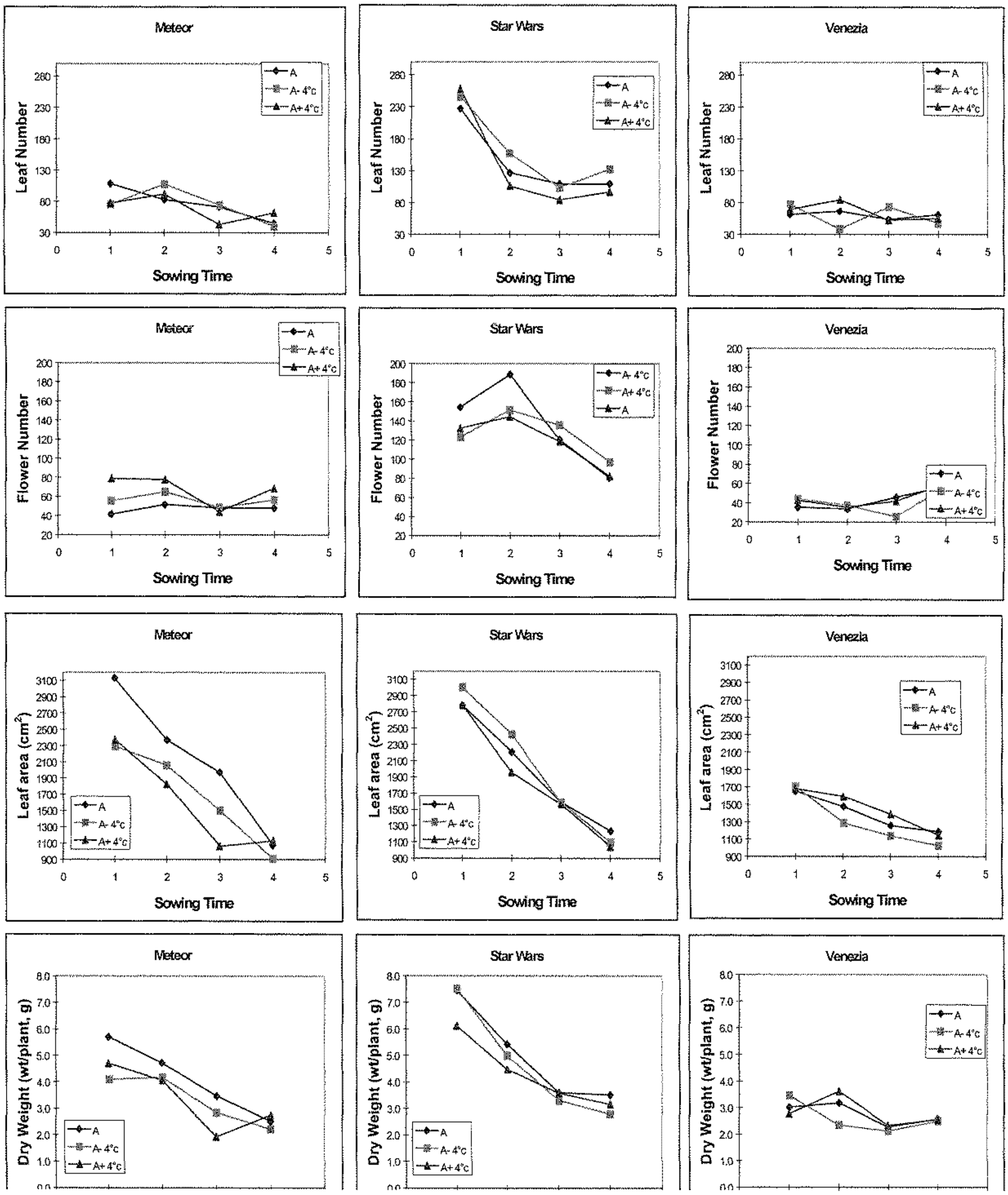
Post, K. (1942). Effects of daylength and temperature on growth and flowering of some florists crops. *Cornell Agr. Exp. Sta. Bull.* **787,** 1-10.

Yeh, D.M. and Atherton, J.G. (1997a). Manipulationn of flowering in cineraria. I. Effects of photoperiod. *Journal of Horticultural Science*, **72,** 43-54.

Yeh, D.M. and Atherton, J.G. (1997b). Manipulation of flowering in cineraria. II. Juvenility. *Journal of Horticultural Science*, **72,** 55-66.

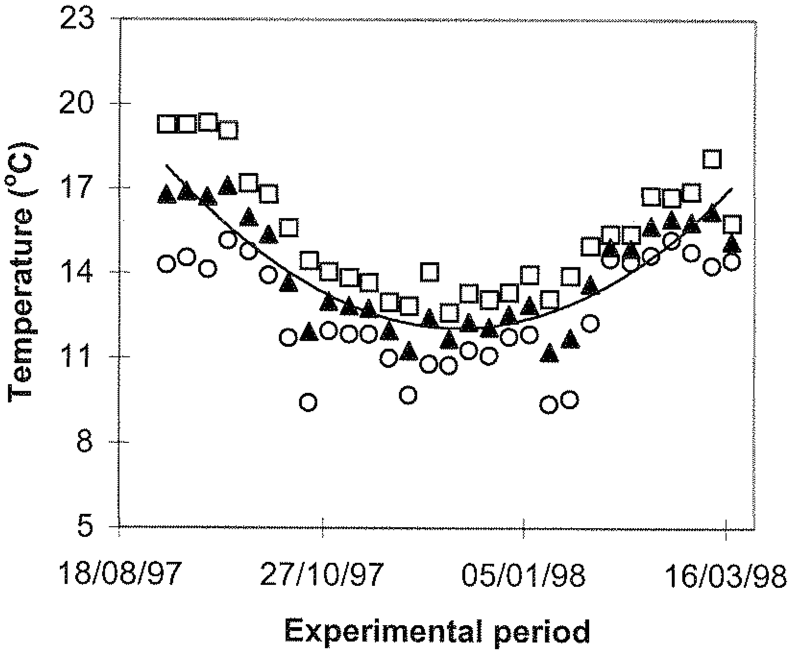
Yeh, D.M., Atherton, J.G. and Craigon, J. (1997). Manipulation of flowering in cineraria. III. Cardinal temperatures and thermal times for vernalisation. *Journal of Horticultural Science*, **72,** 379-387.

APPENDIX 1. A summary of the effects of sowing date and plug production temperature on the growth and quality of cineraria. The sowing dates are as indicated above.



APPENDIX 2. Temperature treatments at the University of Reading. Plants were grown at the temperature (±se) for 21 days.

	Temperature (°C)		
Week Number	normal	warm	cool
33	20.3 (±0.39)	23.2 (±0.2)	14.3 (±0.2)
37	18.7 (±0.25)	21.7 (±0.19)	14.1 (±0.03)
41	14.1 (±0.16)	18.0 (±0.23)	10.1 (±0.17)
49	13.0 (±0.14)	16.3 (±0.04)	9.7 (±0.06)



Temperature variation from the first potting to the last potting at HRI. Circle and square symbols indicate maximum and minimum temperature per week. The triangle symbol is the mean temperature, and the quadratic line indicates the trendline of mean temperature.