Project title	Optimising the propagation environment for endive, escarole, celery and Chinese cabbage
Project number:	FVPC 311
Project leader:	Dr Debbie Fuller, Warwick HRI
Report:	Annual report, December 2008
Previous report	Annual report, December 2007
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Location of project:	Warwick HRI J.E. Piccaver & Co., Lincolnshire. G S Shropshires, Cambridgeshire
Project coordinator:	Mr David Norman
Date project commenced:	01 January 2007
Date project completed (or expected completion date):	December 2009
Key words:	Endive, escarole, celery, Chinese cabbage, propagation, temperature, energy saving, mechanical transplanting

Signed on behalf of: WarwickHRI

Signature: ……… *Simon Bright* ……… Date: …12 January 2009…

Professor Simon Bright
(Director and Head of Department)

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

CONTENTS

Grower Summary

Headline

Wide variations in propagation temperature (from 10°C night to 24°C day) did not increase risk of bolting in the field of celery (cv Victoria), Chinese cabbage (cv 1 Kilo SB), endive (cv Nuance) and escarole (cv Barundi) providing a suitable 24 hour average temperature was maintained indicating potential to use temperature integration to save energy.

Background and expected deliverables

Low temperature can cause bolting (premature flower initiation) in endive, escarole, celery and Chinese cabbage. To reduce the risk of bolting, plants are normally propagated at around 18°C and to delay bolting in the field, the propagator aims to initiate as many leaves as possible to maximise vegetative growth prior to the start of bolting when crops have to be harvested in order to meet quality standards.

In conflict with the requirement to maximise leaf number during propagation, there is increasing demand by growers for smaller plants which are more compatible with mechanical transplanting. There is also a requirement to reduce energy use during propagation due to increased energy costs, as these propagation temperatures are achieved by burning oil or gas. Reducing the production time may increase the risk of bolting as plants will be exposed to 'chilling' earlier (i.e. at a lower leaf number) in the field. The need to reduce energy use and produce smaller plants therefore goes against current strategies to reduce bolting. Information is needed so that growers can make informed decisions concerning the trade-off.

In year one, endive and escarole had higher incidence of bolting than celery and Chinese cabbage. Time of planting and hence external temperatures had the greatest impact on levels of bolting although lower temperature propagation (down to 14°C) also increased bolting. Size of transplant had little impact when external conditions stimulated bolting but where differences were found; larger transplants generally had more bolting. However there was a loss of crops for intermediate planting dates and a change in the strategy for imposing transplant size treatments therefore further work was required.

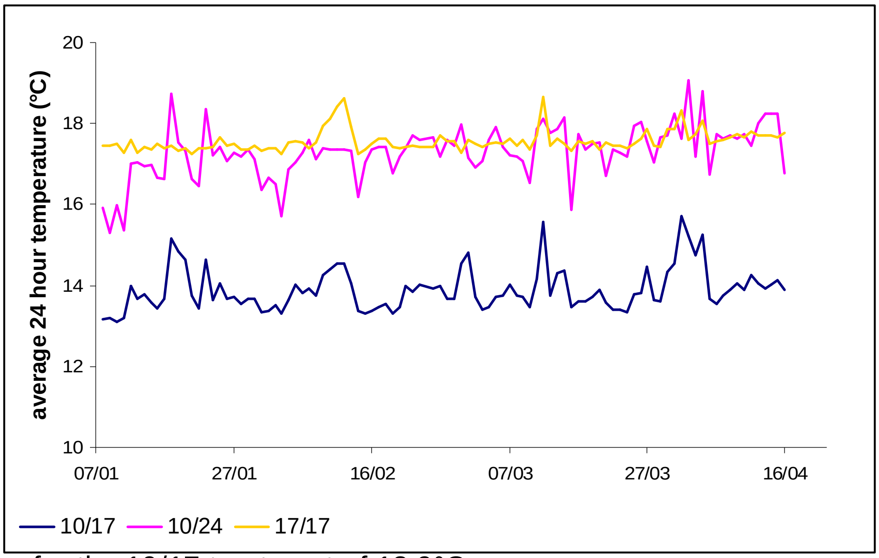
Year two of this project aimed to:

- Determine how incidence of bolting in the field at maturity is affected by variable temperature in propagation to further progress the aim of determining the safe limits for energy saving propagation regimes.

- Continue to examine how reducing the size of transplant influences incidence of bolting in the field at maturity and how this interacts with variable propagation temperature regimes.

Summary of the project and main conclusions

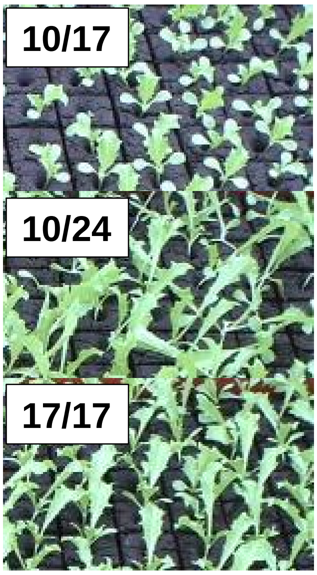
Four species, celery (cv Victoria), endive (cv Barundi), escarole (cv Nuance) and Chinese cabbage (cv 1 Kilo SB) were propagated using three heating regimes: 17°C night and day (17/17), 10°C night and a high day set point (around 24°C) in order to achieve compared 24 hour average to the 17/17 treatment, 10°C night and 17°C day (10/17). Day and night were set to 12 hours each in these experiments and venting was 1°C above set point to keep achieved temperatures as close as possible to target set points. As illustrated in the graph, achieved temperatures in these treatments were comparable between the 17/17 and 10/24 treatments at 17.6°C and 17.3°C respectively, with a lower achieved temperature for the 10/17 treatment of 13.9°C on average.



Six batches of plants were sown to give the range of planting dates summarised in the table below and test how early season production would be affected by propagation temperature and transplant size treatments. The week 10 and 14 batches were planted at the same time as the week 11 and 15 batches respectively but were given a ‘cold shock’ treatment by holding weaned trays of plants outside for one week prior to planting to optimise the chances of generating useful information about bolting should early season temperatures be mild. Sowings were staggered for each planting date in order to produce; (a) ‘standard’ size plants - designed to represent the size of plants produced by commercial propagation, (b) 'large' plants - sown 1 week earlier than the standard and (c) 'small' plants - sown 1 week later than the standard.

Batch/Week no.	No. days in heat			Planting date	Harvest date
	small	standard	large		
Celery					
10(cs)	51	44	37	14/03	18/06
11	51	44	37	14/03	18/06
13	49	42	35	27/03	26/06
14(cs)	41	34	27	10/04	02/07
15	42	35	28	10/04	02/07
17	35	28	21	23/04	16/07
Chinese cabbage					
10(cs)	27	20	13	13/03	19/05
11	27	20	13	13/03	19/05
13	26	19	12	26/03	28/05
14(cs)	23	16	9	09/04	04/06
15	23	16	9	09/04	04/06
17	23	16	9	23/04	11/06
Endive and escarole					
10(cs)	32	25	18	11/03	30/05
11	32	25	18	11/03	30/05
13	28	21	14	27/03	05/06
14(cs)	25	18	11	08/04	12/06
15	22	15	8	08/04	12/06
17	23	16	9	22/04	19/06

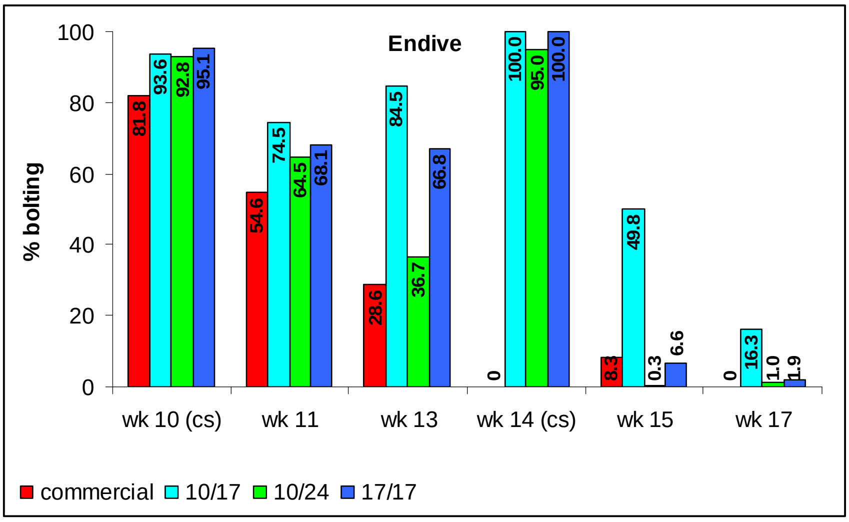
At transplanting stage, keeping plants in the heat for one extra week increased fresh weight by 61 to 157%, plant height by 35 to 59% and visible leaf number by 15 to 46% compared with the size of the standard transplants. Keeping plants in the heat for one week less decreased fresh weight by 52 to 68%, plant height by 31 to 72% and leaf number by 19 to 44%. The variation was caused by species differences which were greater for the more vigorous Chinese cabbage than for celery.



Propagation at an average of around 14°C (i.e. the 10/17 treatment) produced lower shoot fresh weight at weaning whereas propagation at an average of around 17.5°C produced comparable shoot fresh weight whether it was achieved through a fixed 17/17 regime or through a more variable 10/24 regime. Hence it appears that the average temperature was more important than the night temperature in these treatments. The high day temperatures of the 10/24 treatment however resulted in plant stretch as illustrated in the photograph for endive, and therefore this regime has potential to create quality issues for the propagator.

Following propagation treatments in glasshouses at WHRI Wellesbourne, plants were transplanted on to commercial farms for growing on. Chinese cabbage and celery were grown on at G.S. Shropshires and endive and escarole at J.E. Piccaver & Co. Harvest and therefore final assessment date was determined by the commercial harvesting date for each batch of plants.

Bolting in celery and Chinese cabbage was limited to the earliest batches of plants (planted in week 10 and 11) whereas there was some bolting in all batches of endive and escarole (as illustrated in the graph). Where levels of bolting were very high (89%+) or very low (0–3%), propagation temperature made no difference to levels of bolting. However, between these extremes of percentage bolting, lower propagation temperature (10/17) increased levels of bolting. Higher propagation temperature gave no more bolting when given as a variable 10/24 regime than as a more stable 17/17 regime, despite the low night temperature of 10/24 treatment. In some cases, there was less bolting in the 10/24 regime than in the 17/17 regime suggesting some potential for high



temperature reversal of prior low temperature induction. The 10/24 treatment was either no different to the 17/17 treatment for head weight at harvest, or in the case of celery, had lower head weight than the 17/17 treatment which suggests this variable temperature regime would have either no impact on production times, or for celery may require slightly longer in the field to achieve target head weight. There is therefore clearly potential for using variable temperature regimes as an energy saving strategy to produce transplants without impacting bolting. It is expected that the plant stretch resulting from the 10/24 treatment may be reversed using a low day and higher night approach to improve transplant quality which could also increase energy savings for propagators that have thermal screens available; this will be tested in 2009 along with temperature integration settings.

When plants were harvested on a set date, corresponding to the timing of commercial harvests, smaller transplants had less bolting than larger ones. This trend occurred in all species although, as with temperature, transplant size had no influence on batches where there were either extremely high or low levels of bolting. Interpretation of this result is complicated by the fact that in practise, growers would harvest plants when they reach a suitable size and hence date of harvest may be expected to be sooner for the larger transplants than the smaller ones. Differences in head weight might be expected to resolve this complication and larger transplants in some batches of celery, endive and escarole did produce significantly greater head weight. However these differences were not consistent over all species and batches and so whilst the suggestion is that smaller transplants may be acceptable for early season production, levels of bolting in plants harvested at a similar size rather than on a set date needs to be assessed. This will be addressed in 2009 by including plots which can be checked regularly and harvested by treatment according to head weight.

Financial benefits

Results from the final year of studies are required to confirm the use of temperature integration for the propagation of these species. Assuming temperature integration can be used; estimates from other sectors of the industry suggest energy savings of around 10 % may be achieved. Actual savings will depend on settings applied. Beyond the very earliest planting weeks of the season, celery and Chinese cabbage for example, may be propagated at lower average temperature although this would not be suitable for the more sensitive endive and escarole. The slow rate of production of celery may however limit lower temperature propagation due to potential impact on throughput unless there is potential to trade this against the use of smaller transplants.

Savings from changes in transplant size would be related to reduction in speed of throughput and hence energy input per batch as well as improved efficiency during transplanting and potential to reduce losses resulting from damage suffered in mechanical transplanters. Smaller transplants should separate more readily when being fed into the transplanting equipment and therefore speed up rate of planting. Reduction in losses has potential to increase yield since damaged plants are likely to be slower to establish and therefore may compete less well with neighbouring plants as well as reduce the need for fungicide sprays by reducing sites of entry for pathogens.

Action points for growers

- Celery (cv Victoria) and Chinese cabbage (cv 1 Kilo SB) have tolerated lower (14°C) propagation temperature with little impact on plantings beyond week 14 suggesting risk of bolting need not constrain heating set points for these varieties.

- Endive (cv Barundi) and escarole (cv Nuance) are clearly more sensitive to premature bolting and require more conservative average propagation temperature. Potential for energy saving by allowing temperature to fluctuate between as low as 10°C and up to 24°C exists for these varieties as well as for celery and Chinese cabbage providing a suitable average temperature is maintained.

- Temperature treatments in these experiments were designed to examine the worst case scenario of the set points used by keeping vent set point close (i.e. 1°C) to heat set points. In practise growers should choose a higher vent set point which would be more energy efficient and would be expected to result in higher average temperatures than were achieved in the work described here.

- Small transplants had less bolting at a set harvest date than larger ones but in some cases also had lower head weight. The influence of varying harvest date in order to account for differences in plant size at harvest needs to be further assessed before the impact of reducing transplant size can be fully evaluated.

Science Section

Introduction

Low temperatures can cause bolting (premature flower initiation) in endive, escarole, celery and Chinese cabbage. To reduce the risk of bolting plants are normally propagated at around 17-18°C and to delay bolting in the field, propagators aim to initiate as many leaves as possible to maximise vegetative growth prior to the start of bolting.

With the rapid increase in gas and oil prices there has been increasing pressure to reduce energy use. There is a fear that reducing production temperatures may increase the risk of bolting, however, little information is available. Temperature integration (TI) which allows fluctuation in instantaneous temperatures providing longer term averages are met, has successfully been adopted for various protected crops. Temperatures above conventional set-point levels resulting from solar gain are offset against lower temperatures in overcast weather or at night reducing heat required from the boiler. In crops tested so far, the risks of using temperature integration have been related to yield, timing and quality. However crops susceptible to bolting have not been considered and so it is unclear whether allowing greater temperature fluctuations and, therefore, periods of low temperature will increase the risk of bolting.

In conflict with the requirement to maximise leaf number during propagation as outlined above, there is increasing demand by growers for smaller transplants which are more compatible with mechanical transplanting. Reducing transplant size may increase the risk of bolting as plants will be exposed to 'chilling' earlier (i.e. at a lower leaf number) in the field. The need to reduce energy use and produce smaller plants therefore goes against current strategies to reduce bolting. Information is needed so that growers can make informed decisions concerning the trade-off.

Whilst studies relating to temperature integration and bolting are lacking, there is information from the literature regarding flower initiation of the species included in this project. Wurr (1996) has shown how conditions in propagation will have a carry over effect into the field in terms of progression towards flowering. The aim of commercial propagators is therefore to ensure young transplants have not been triggered to flower before leaving the nursery, although once in the field, flowering may be rapidly initiated by low temperature early in the season and by increasing daylength. Hence with smaller transplants that have fewer leaves initiated prior to transplanting it is particularly important that transplants are either juvenile or vegetative with minimum progression towards flowering when planted out. Crop management may then be used in the field to ensure that plants are harvested before signs of bolting become visible.

All species covered by this project are triggered to flower by either low temperature or long days (Friend, 1985; Paulet, 1985; Pressman and Sachs, 1985) although the relative importance of these factors varies with species and variety. Low temperature is the predominant factor influencing flowering in Chinese cabbage although effective temperatures and duration of chilling varies with cultivar and also daylength. Once induced, flowering is then hastened by LD. High temperature may also reverse induction suggesting that the high-day / low-night temperature regimes may work well for both energy saving and minimizing bolting. Elers and Wiebe (1984) demonstrated how high day temperature combined with low night temperature delayed bolting in comparison with low temperature both day and night. However in these studies, average 24 hour temperature varied which also affected parameters such as head dry weight.

Low temperature (5-10°C) is also reported to be the predominant factor influencing flowering in celery with temperatures above 14°C required to prevent induction and with potential to use high temperature to delay the effects of previous low temperature induction. LDs during induction of celery prevent bolting but then after induction, LDs promote bolting. Since propagation temperatures are designed to prevent induction, introducing LD lighting is unlikely to be useful in celery propagation. For endive and escarole most of the work from the Handbook of Flowering was carried out on plants in vitro. These studies again point to low temperature hastening flowering (although not an absolute requirement particularly in early varieties), but unlike the other species covered previously, varieties of *Cichorium intybus* and *C. endivia* also required LD to flower (Paulet, 1985; Gianquinto, 1997).

If species need to be propagated in common conditions, then temperature would need to be above that of the highest requirement to prevent induction, and variable temperature regimes to save energy may be acceptable given that the higher temperatures accumulated for part of the day may be effective in delaying/reversing induction in plants exposed to lower temperature at other times of the day or if plants integrate and respond to the average. Daylength control however may be less suited to compromise, whilst LD lighting may be suitable for celery (at least until it is induced to flower), for *C.intybus* flowering may be promoted.

In order to respond to triggers for flowering, plants must have completed their juvenile phase and data to support this information can be less reliable. For *C.intybus*, plants were capable of responding to daylength 2-3 weeks from germination (Paulet, 1985) which suggests the juvenile phase may end before the end of the commercial propagation period and hence temperature and daylength during propagation may be expected to have an impact on subsequent bolting as well as environmental conditions that the young plants are exposed to following transplanting. For celery, imbibed seeds were capable of being vernalized (Ramin & Atherton, 1991a) but a juvenile period has also been reported (Ramin & Atherton, 1991b) if imbibed seeds are not exposed to low temperature (which is likely to be the case for commercial propagators). For *C.intybus* anti-vernalization was achieved through exposing imbibed seed to higher temperature, which is effective in pre empting the later effects of low temperature, although high temperatures during germination may reduce emergence rates (Gianquinto and Pimpini, 1989). For Chinese cabbage, sensitivity to inductive conditions from germination has also been reported (Friend, 1985; Elers and Wiebe, 1984). Overall it appears that the species covered by this project may be expected to be receptive to inductive conditions for at least part of the propagation period (3 to 7 weeks depending on species and sowing date) highlighting the requirement for work to determine the safe limits in order to benefit from energy saving strategies during propagation.

In the first year of this project, propagation at 14 or 16 °C rather than 18°C increased levels of bolting in endive and escarole in particular and also in Chinese cabbage very early in the season. No bolting was recorded for celery which may in part be due to the relatively mild early season conditions in 2007. Apical dissections indicated that transplants from all temperature regimes were vegetative at transplanting stage but that endive and escarole plants at least may have progressed further towards flowering following propagation at lower temperature than at higher temperature, which agrees with the data collected at harvest stage. Hence reducing propagation temperature to save energy is expected to increase bolting of at least two of the species studied. In the most extreme conditions however, where there were high levels of bolting; propagation temperature had relatively little impact on levels of bolting. Experiments in year 2 were therefore designed to see if moving towards a variable temperature regime would be a more suitable strategy for these crops, with extra treatments included to give some plants an extra low temperature ‘challenge’ prior to planting out in order to maximize the chances of creating bolting.

Results for transplant size in 2007 were less clear cut. There was a suggestion that larger transplants of endive and escarole may increase bolting for plants harvested on a set date.

However in practice these larger transplants may have been harvested earlier which could then reduce levels of bolting. The first step is to verify these results in the trials in the year 2 (2008) experiments described here.

Materials and methods

Treatments:

Three internal 43m² glasshouse compartments of a linear array were set to one of the propagation temperature treatments:

- 17°C night and day (17/17) as a control
- 10°C night with day set to achieve the same 24 hour average as the 17/17 treatment i.e. typically around 24°C (10/24)
- 10°C night and 17°C day (10 /17) as a low night treatment with no day heat boost resulting in a lower 24 hour average temperature than the first two treatments.

Day and night were set as 12 hour periods from 06:00 to 18:00 and from 18:00 to 06:00.

Sowings were staggered for each planting date in order to produce;

- ‘standard’ size plants - designed to represent the size of plants produced by commercial propagation,
- ‘large’ plants - sown 1 week earlier than the standard
- ‘small’ plants - sown 1 week later than the standard.

The following propagation schedule was applied to provide 6 batches of plants:

Batch/Week no.	No. days in heat			Planting date	Harvest date
	small	standard	large		
Celery					
10(cs)	51	44	37	14/03	18/06
11	51	44	37	14/03	18/06
13	49	42	35	27/03	26/06
14(cs)	41	34	27	10/04	02/07
15	42	35	28	10/04	02/07
17	35	28	21	23/04	16/07
Chinese cabbage					
10(cs)	27	20	13	13/03	19/05
11	27	20	13	13/03	19/05
13	26	19	12	26/03	28/05
14(cs)	23	16	9	09/04	04/06
15	23	16	9	09/04	04/06
17	23	16	9	23/04	11/06
Endive and escarole					
10(cs)	32	25	18	11/03	30/05
11	32	25	18	11/03	30/05
13	28	21	14	27/03	05/06
14(cs)	25	18	11	08/04	12/06
15	22	15	8	08/04	12/06
17	23	16	9	22/04	19/06

To produce an extra low temperature challenge (or cold shock), two batches of the plants sown were stood outside for one week after hardening off without fleece protection before transplanting into the field. These batches are labelled (cs) in the batch/week no. column of the above table. Although the schedule indicates week 10 and week 14 for planting these two batches of plants, they were actually planting the following week but were exposed to external temperatures in the week number indicated.

Germination times were 5 days for celery, 4 days for endive and escarole and 3 days for Chinese cabbage. Plants were given 5 days for weaning in a protected structure with frost prevention.

The effects of the three propagation temperature and the three plant stage treatments were compared on four species grown for early season production i.e. celery (cv Victoria), Chinese cabbage (cv 1 Kilo SB), escarole (cv Nuance) and endive (cv Barundi).

In summary, treatments compared:

3 propagation temperatures

x

3 stages of plant development at transplanting

x

4 species

x

6 batches of plants

giving 36 treatment combinations which were each replicated over two block trays during propagation and over four plots when planted into the field for each of the 6 batches.

Details of agronomy and environmental control

Seed sourced from commercial suppliers (and primed in the case of celery) were sown in standard peat blocks produced by Hillgate Nursery, Terrington St Clement, Norfolk and transported to Wellesbourne for the experiments. Seed of all species were sown one per peat block by hand.

Trays were stacked in piles for germination in an air conditioned glasshouse compartment set to 18°C day and night. An empty tray was used at the top of each stack in order to achieve comparable levels of lighting to all trays when arranged in these stacks. Stacks were wrapped with clear polythene to prevent drying out during germination.

Trays were moved to compartments to receive temperature treatments once seed had chitted and signs of emergence were just visible.

Venting was +1°C above heating set point in all compartments to ensure target temperatures were achieved in order to test the worse case scenario of the set points tested. In practise, growers would use higher vent set points which would be more energy efficient.

The first 2 batches of trays were not watered until 10 days after sowing. Care was needed not to over-water early on, although water requirements increased once the cotyledons had expanded. Later batches of trays needed a very light watering after transferring to compartments using a fine rose. Subsequent watering was by hand overhead as needed with borehole water.

Routine sprays for prevention of fungal or insect infections were as follows:

> Chinese cabbage – Chlorpyrifos to prevent cabbage root fly for any batches planted out after 1st March (and therefore without fleece covers)
>
> Endive and escarole - Rovral WP spray for botrytis control in the week before planting
>
> Celery - Amistar and Bravo, for Septoria control applied a week apart starting two weeks from weaning.

After weaning, plants were transported to the commercial sites for planting out. Celery and Chinese cabbage were planted at Shropshires, on organic soils near Feltwell, Norfolk, and endive and escarole were planted at Piccavers on silty soils near Holbeach, Lincolnshire. Blocks were planted into field plots using pre-dibbed holes at Piccavers, or by creating space to plant blocks manually at Shropshires. In both cases blocks were planted so that the surface of the peat block was approximately level with the surface of the soil. Field plots varied in location at each commercial site to ensure plants from experiments would be grown alongside those raised for commercial production which ensured experimental plots would receive identical management to commercial crops (i.e. irrigation, fleecing and pesticide treatment). This meant that a fully randomised design to account for batch effects could not be used for field plots from different planting dates. Plots of commercially produced plants were therefore planted alongside plants raised in experimental treatments to provide some benchmark information within each batch.

All batches of plants were covered with fleece after planting out for frost protection

Experimental layout:

Propagation treatments were given in three 43 m² glasshouse compartments in a linear array. The compartment with highest day temperature (10/24) was in the centre of the three with the lower day temperatures on either side. The benches in each of the glasshouse compartments were divided in half lengthways with each half bench dedicated to a species. Trays were placed on the south end of the bench initially and moved down towards the north end of the bench as each new batch moved into a compartment. There were 2 replicate trays of 150 plants per tray for each combination of species/sowing date/ transplanting date/propagation temperature.

The bed layout in the field was different on each site due to differences in bed preparation. At Piccavers a triple bed former, had been used which produced 6 beds with 4 staggered rows per bed. At Shropshires prepared beds were in rows of 12 rows wide. An example of the plan for each site is given in figures 1 and 2.

All plantings were laid out using a randomised block design where each of the four blocks had a complete set of treatments as well as a plot of commercially raised plants. Individual plots consisted of 12 rows of plants with four plants per row. Edge plants in each plot served as guard plants with 20 fully guarded plants in the centre of each plot for experimental records. Each batch of plants was further guarded by commercial material on all sides.

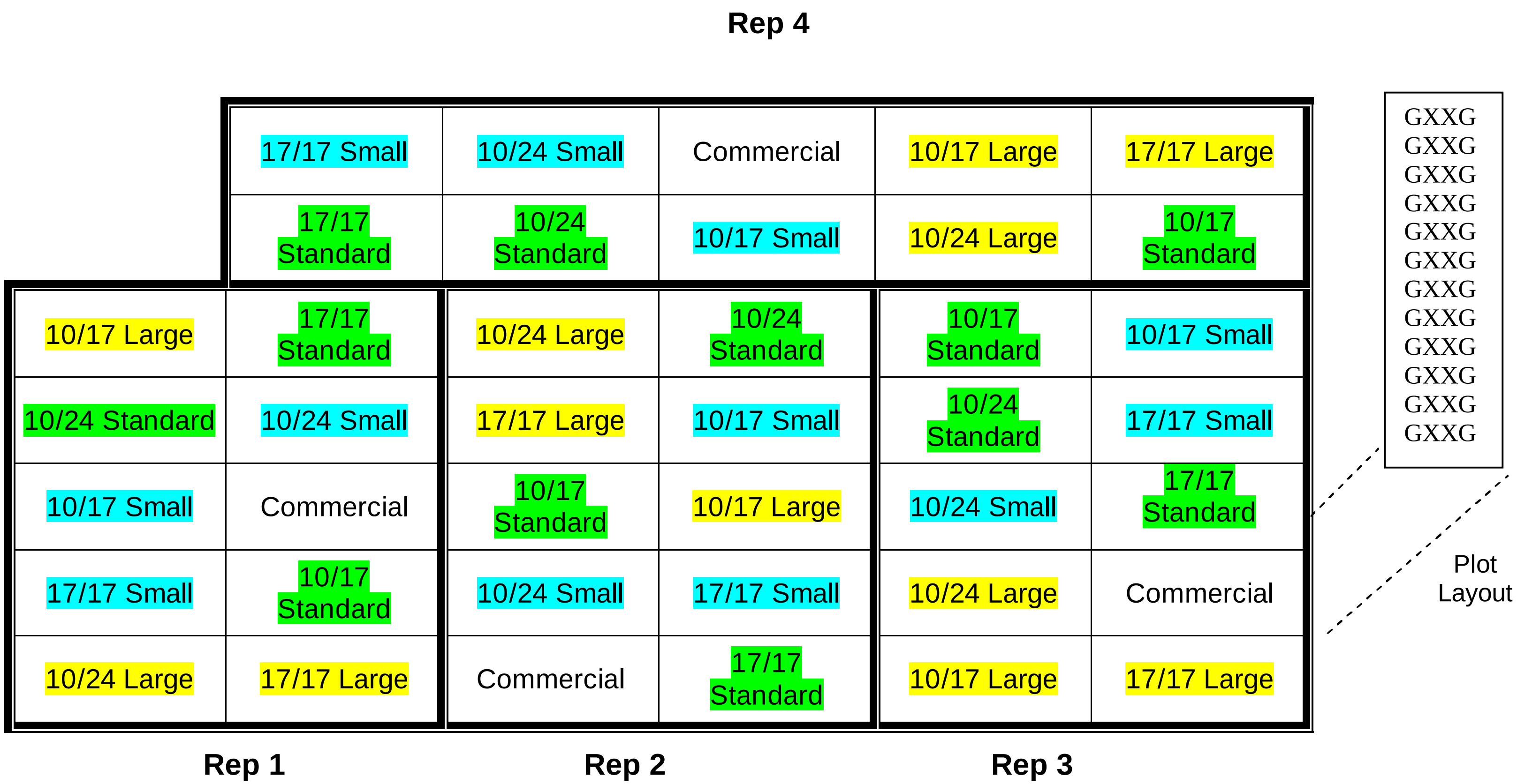


Figure 1. Plan of plot design at Piccavers. 17/17, 10/24 and 10/17 represent propagation temperatures; small, standard and large refer to transplant size; G represents guard plants and X represents plants sampled for assessment in the detailed plot layout plan

10/17 Large	17/17 Standard	10/24 Large	10/24 Standard	10/17 Standard	10/17 Small	17/17 Large	10/17 Standard
10/24 Standard	10/24 Small	17/17 Large	10/17 Small	10/24 Standard	17/17 Small	10/17 Large	10/24 Large
10/17 Small	Commercial	10/17 Standard	10/17 Large	10/24 Small	17/17 Standard	Commercial	10/17 Small
17/17 Small	10/17 Standard	10/24 Small	17/17 Small	10/24 Large	Commercial	10/24 Small	10/24 Standard
10/24 Large	17/17 Large	Commercial	17/17 Standard	10/17 Large	17/17 Large	17/17 Small	17/17 Standard

Rep 1 **Rep 2** **Rep 3** **Rep 4**

GXXG
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Plot layout

Figure 2. Plan of plot design at Shropshires. 17/17, 10/24 and 10/17 represent propagation temperatures; small, standard and large refer to transplant size; G represents guard plants and X represents plants sampled for assessment in the detailed plot layout plan

Monitoring and assessment

Achieved temperatures in germination, experimental compartments and weaning areas were logged throughout the experiment. Data loggers were placed in selected field plots at planting.

Plant assessments were made prior to transplanting, recording the following parameters:

- Shoot fresh weight
- Shoot height (as length of longest leaf)
- Visible leaf number (all leaves above 2mm length)

A photographic record was kept of all treatments in trays prior to transplanting.

Final assessments in the field were made approximately one week after commercial plants surrounding each plot were ready for harvest, recording the following parameters:

- Number of plants per plot bolted
- Head weight
- Apex length of plants dissected longitudinally (celery and Chinese cabbage)

Results

Environmental data

Glasshouse temperature

The 10/24 and 17/17 treatments achieved comparable 24 hour mean temperature (figure 3). The change over from 24 to 10°C at the end of night generally took around 2-4 hours to achieve given limitations of venting systems as well as the influence of external environment, e.g. a mild night would limit the required drop in temperature to 10°C (figure 4). Hence the achieved temperatures for the 10/24 treatment were more variable over the period of the experiment than for the 17/17 treatment. The program used to align achieved temperature in these two higher temperature treatments adjusted the current set points in the 10/24 compartment according to the achieved temperature in the 17/17 compartment the previous day and hence there was a 24 hour lag in this adjustment. Over the whole experiment, the achieved average 24 hour temperature was 17.6°C in the 17/17 treatment, 17.3°C in the 10/24 treatment and 13.9°C in the 10/17 treatment.

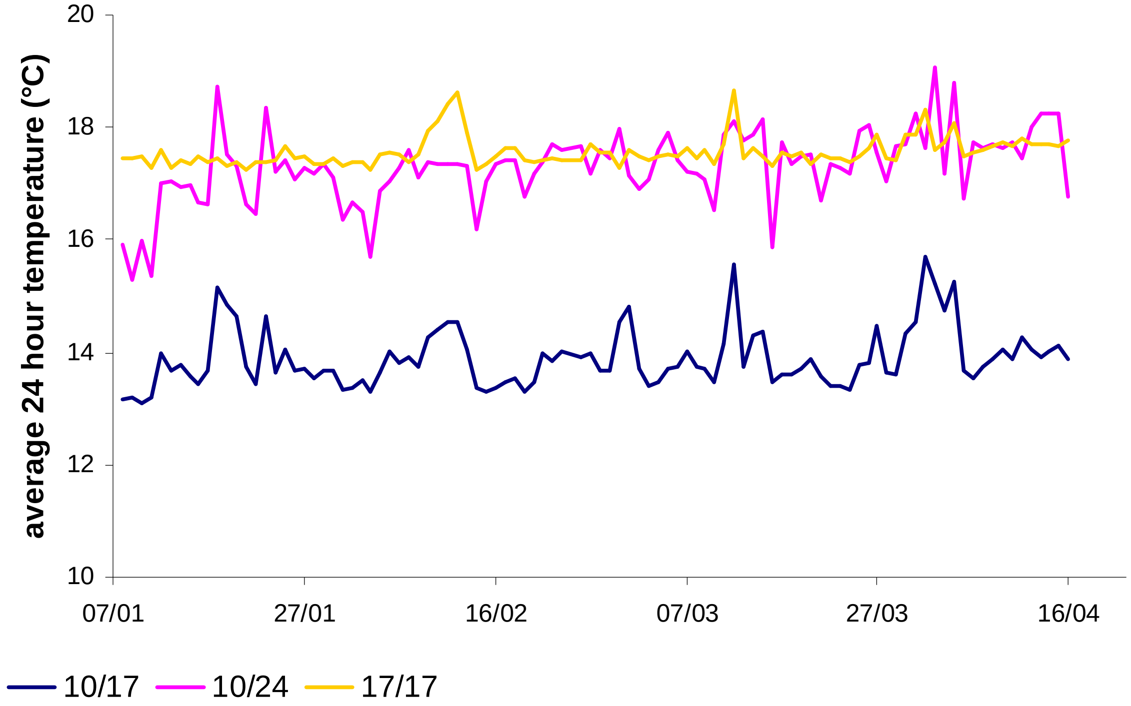

Figure 3. Average achieved temperature in the three compartments during propagation of the six batches of plants

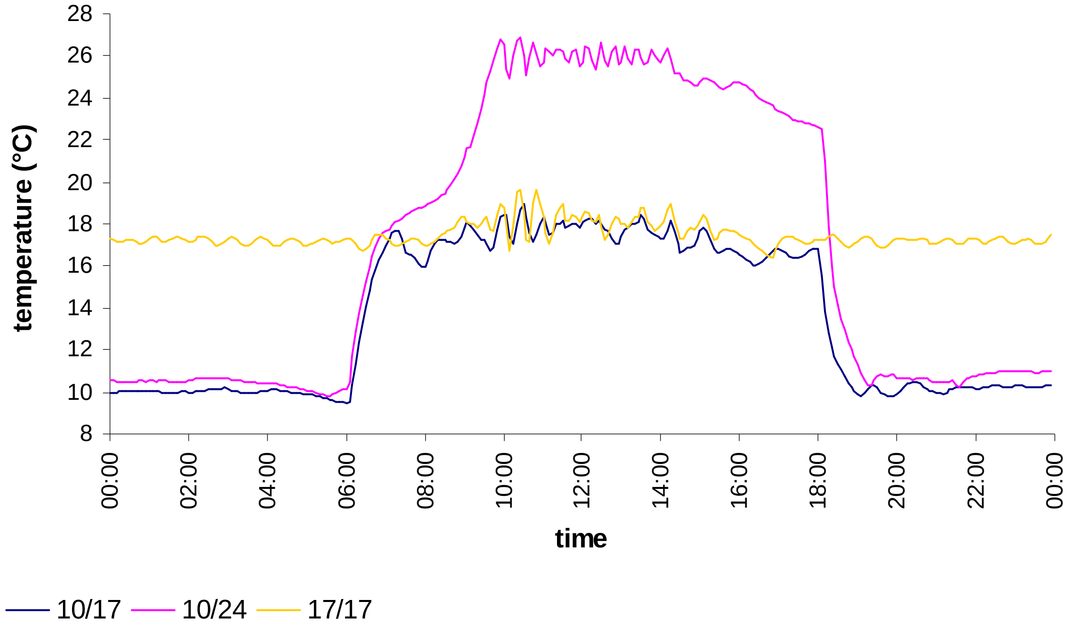

Figure 4. Instantaneous temperatures in the three propagation treatments on 30/01/08.

Whilst temperatures in glasshouse compartments remained relatively stable, the average temperature perceived by transplants during propagation varied with transplant size and hence length of time spent in heated compartments prior to weaning (table 1). Larger transplants that spent the greatest amount of time in propagation had slightly higher (up to 1.5°C) average temperature in propagation when the weighted averages (i.e. cumulative mean temperature / days spent in the compartments) are compared.

Table 1. Achieved weighted average temperature of treatments between germination and weaning

		Celery			Chinese cabbage			Endive and escarole		
Plant week	**Transplant size**	**10/17**	**10/24**	**17/17**	**10/17**	**10/24**	**17/17**	**10/17**	**10/24**	**17/17**
10cs	**small**	12.7	14.9	15.1	11.3	12.9	12.9	12.0	13.8	14.0
	standard	12.8	15.1	15.4	11.8	13.7	13.8	12.3	14.3	14.5
	large	12.9	15.2	15.6	12.1	14.1	14.4	12.5	14.7	14.9
11	**small**	13.3	15.8	16.1	12.8	14.7	14.7	13.0	15.3	15.4
	standard	13.4	16.0	16.2	13.0	15.3	15.4	13.2	15.6	15.9
	large	13.5	16.1	16.4	13.2	15.6	15.8	13.3	15.8	16.1
13	**small**	13.1	15.7	15.8	12.2	14.0	14.1	12.2	14.0	14.1
	standard	13.2	15.9	16.1	12.6	14.9	15.0	12.5	14.7	14.8
	large	13.3	16.0	16.2	12.8	15.4	15.4	12.7	15.1	15.2
14cs	**small**	12.8	14.9	15.0	11.8	13.3	13.3	12.2	13.8	13.8
	standard	13.0	15.2	15.3	12.3	14.2	14.2	12.6	14.5	14.6
	large	13.0	15.5	15.6	12.6	14.7	14.8	12.8	15.0	15.0
15	**small**	13.6	16.0	16.1	13.1	14.8	14.8	13.7	15.2	15.2
	standard	13.6	16.2	16.3	13.2	15.5	15.5	13.6	15.8	15.9
	large	13.7	16.4	16.5	13.5	15.9	16.0	13.8	16.2	16.3
17	**small**	14.0	16.3	16.2	13.3	15.1	15.0	13.5	15.4	15.3
	standard	13.9	16.4	16.4	13.6	15.9	15.8	13.8	16.0	15.9
	large	13.9	16.6	16.6	13.7	16.2	16.2	13.8	16.3	16.3

Field temperature

Temperature after propagation was determined by external conditions which varied with batch as illustrated for Chinese cabbage (figure 5), since each batch of all species was planted in the same week these data indicate the environment experienced by all species.

Achieved temperatures for the initial 3-4 weeks after planting in the field were higher for the later batches of plants (planted week 14 to 17) than the earlier ones (planted week 10 to 13).

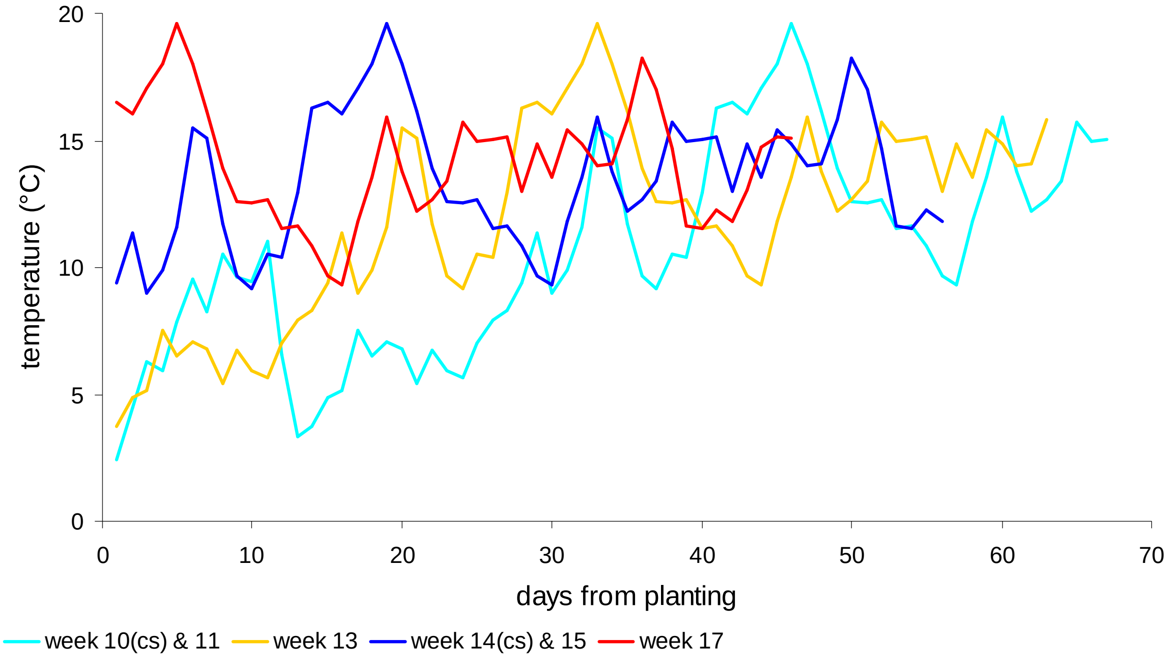

Figure 5. Comparison of achieved temperatures in the field after planting six 6 batches of Chinese cabbage between week 11 and week 17 2008

Assessments at transplanting stage

Transplant size

Varying the length of propagation to produce different sizes of transplant influenced shoot fresh weight, visible leaf number and height. As would be expected, plants propagated for one week longer than 'standard' commercial practice (i.e. the large transplants) were 0.3 to 2.9g heavier than the smallest transplants (grown for one week less than standard commercial practice), they also had between 2.0 and 5.6 more visible leaves and were 5.5 to 11.4 cm taller (Figures 6-8).

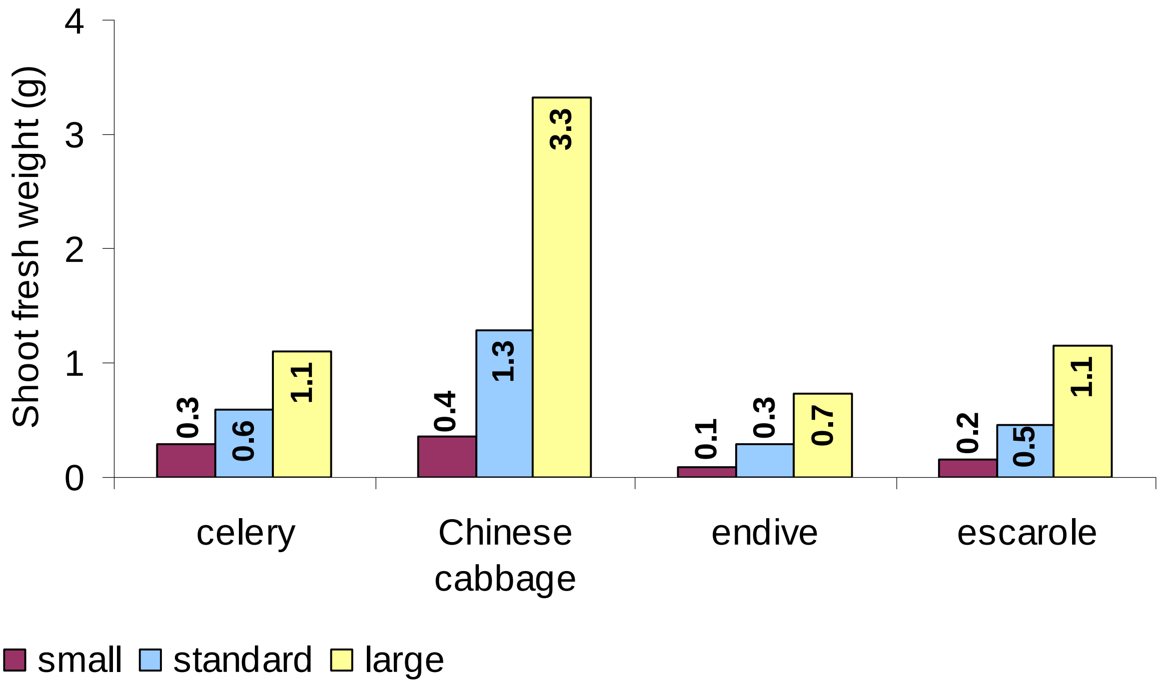

Figure 6. The influence of transplant size on shoot fresh weight of celery (l.s.d. P<0.05 = 0.04), Chinese cabbage (l.s.d. P<0.05 = 0.11), endive (l.s.d. P<0.05 = 0.03) and escarole (l.s.d. P<0.05 = 0.05) at the end of propagation

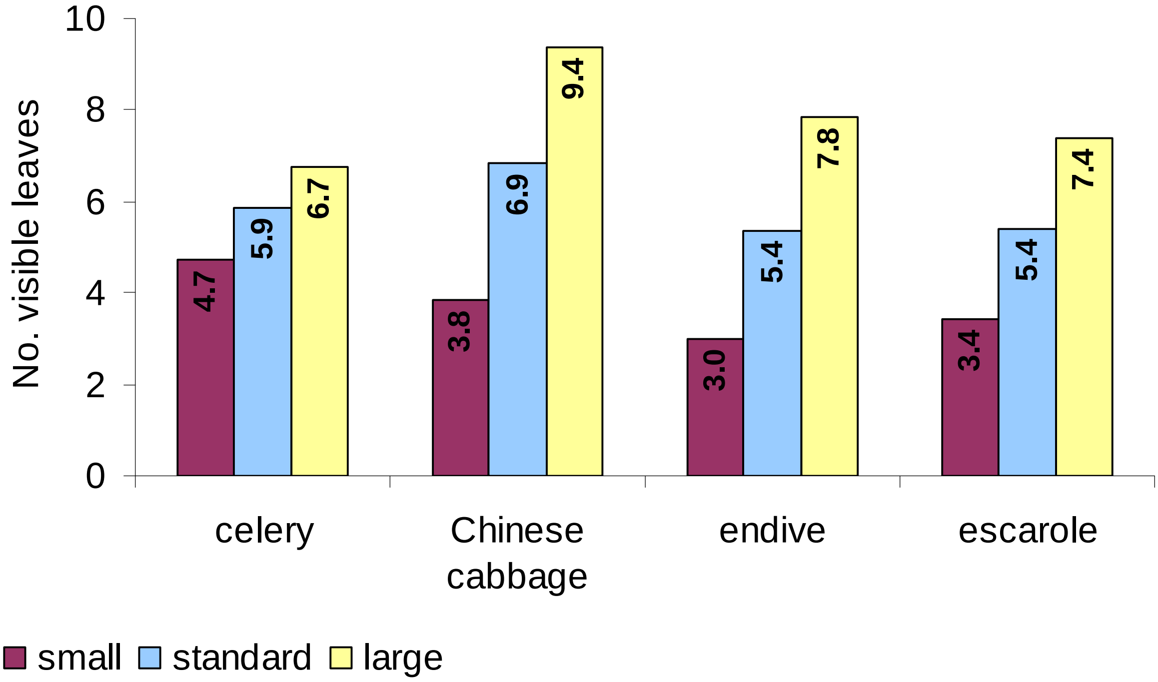

Figure 7. The influence of transplant size on visible leaf number of celery (l.s.d. P<0.05 = 0.15), Chinese cabbage (l.s.d. P<0.05 = 0.19), endive (l.s.d. P<0.05 = 0.20) and escarole (l.s.d. P<0.05 = 0.16) at the end of propagation

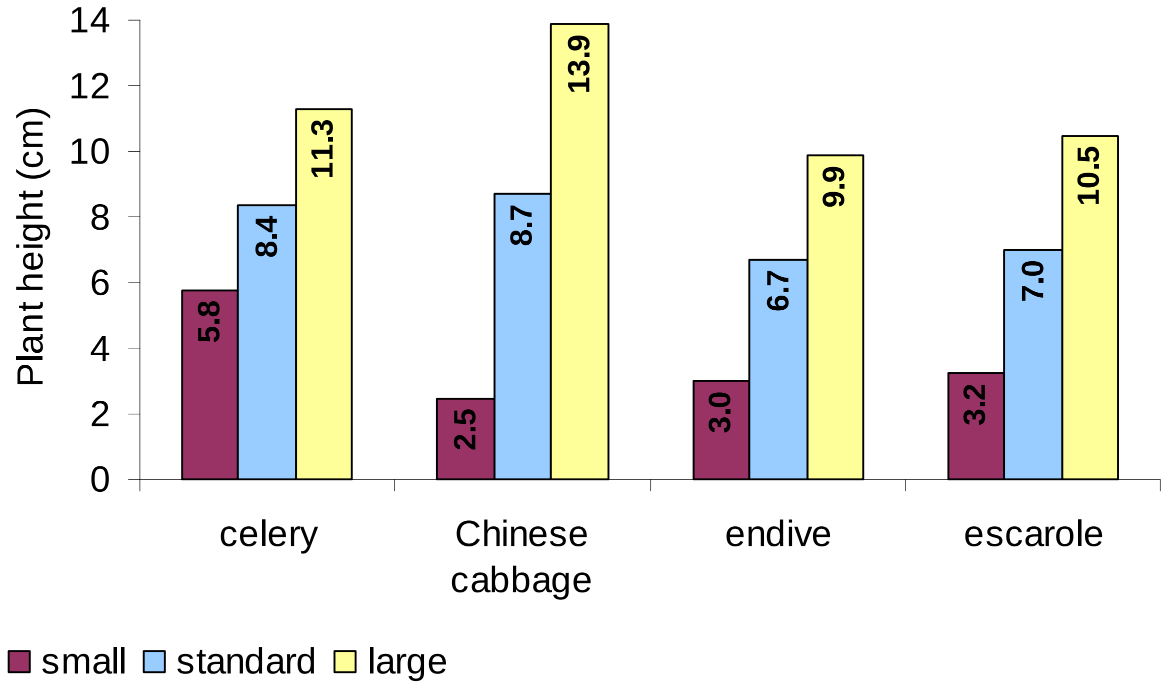

Figure 8. The influence of transplant size on height of celery (l.s.d. P<0.05 = 0.23), Chinese cabbage (l.s.d. P<0.05 = 0.21), endive (l.s.d. P<0.05 = 0.18) and escarole (l.s.d. P<0.05 = 0.24) at the end of propagation

Interaction between transplant size and batch

Schedules were designed to produce three transplant sizes at each of six planting dates with timings of the standard crop designed to follow commercial schedules for the same planting weeks. As indicated in figure 9, whilst transplant size treatments were different from each other within each batch as planned, there was some batch to batch variability. This included a reduction in size of standard plants over time where commercial schedules are typically shortened to account for improvements in the weather as the season progressed. Another factor that varied over time was the difference between the three sizes of transplant; in particular the larger transplants became proportionately bigger relative to the standard transplants. This was presumably a result of the extra growth possible in 7 days increased as the season progressed. The differences in plant size from batch to batch are illustrated in the Appendix which contains photographs of all treatments at weaning stage.

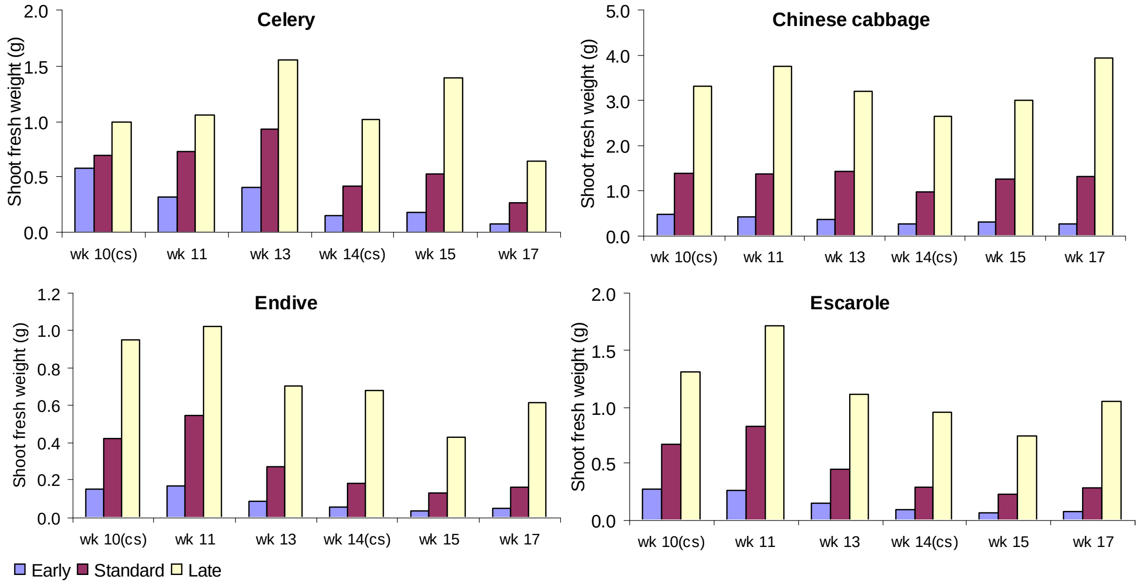

Figure 9. The interaction of batch and transplant size on shoot fresh weight at weaning stage (l.s.d. (P<0.05) = 0.14 celery, 0.27 Chinese cabbage, 0.07 endive and 0.13 escarole)

Propagation temperature

Propagation temperature had a significant (P<0.05) influence on transplants. In general, the highest average temperature (i.e. 10/24 and 17/17) produced the largest transplants. Shoot fresh weight was 0.2 to 0.6g heavier (i.e. 38 to 150% heavier), plants had up to 1.6 more leaves and were 2.1 to 4.2 cm taller in the 17/17 and 10/24 treatments compared with 10/17 (figures 10-12). Fresh weights from the 10/24 and 17/17 treatments were similar for endive and Chinese cabbage but were higher for celery at 17/17 and higher for escarole at 10/24. The 17/17 treatment produced higher leaf number than 10/24 for all four species. Plant height however was generally greater for the 10/24 treatment than the 17/17 treatment which was probably linked to the higher temperature in the day (sometimes referred to as positive DIF). This stretch response to high day temperature has been demonstrated in other species and could result in quality issues, however in practice propagators would have less extreme differences in achieved temperatures than in this experiment where vent temperature was close to heating set point in order to assess worse case scenarios. Celery was an exception to this general trend with taller plants from the 17/17 treatment than the 10/24 treatment.

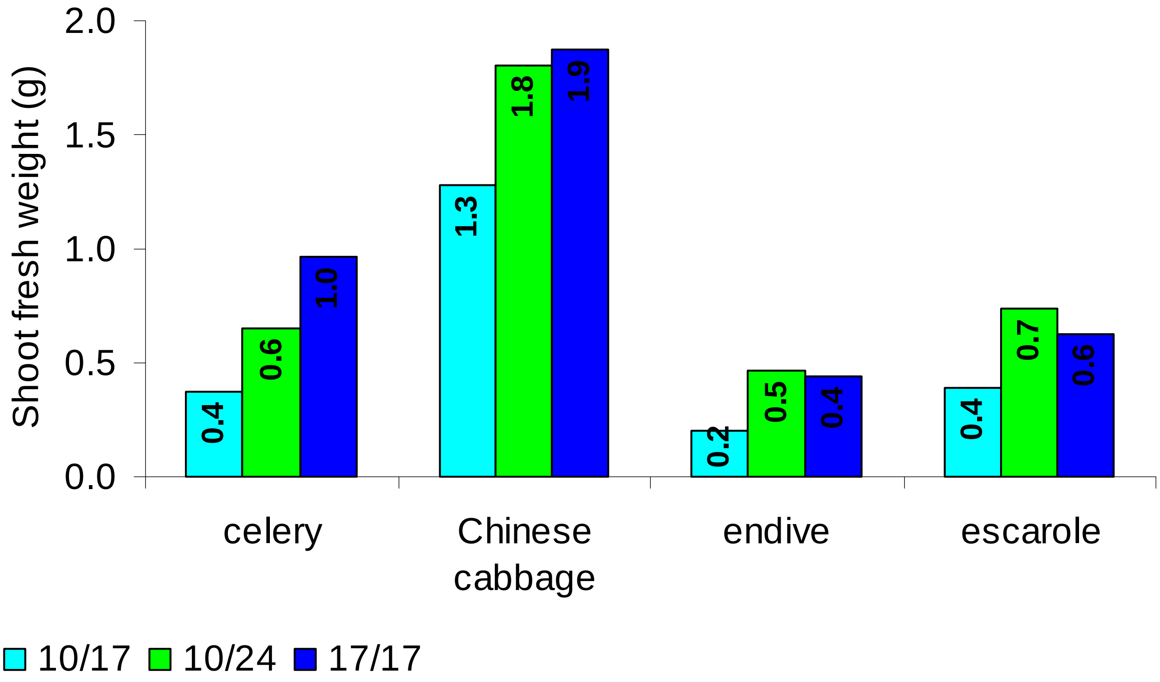

Figure 10. The influence of propagation temperature on shoot fresh weight of celery (l.s.d. P<0.05 = 0.04), Chinese cabbage (l.s.d. P<0.05 = 0.11), endive (l.s.d. P<0.05 = 0.03) and escarole (l.s.d. P<0.05 = 0.05) at the end of propagation

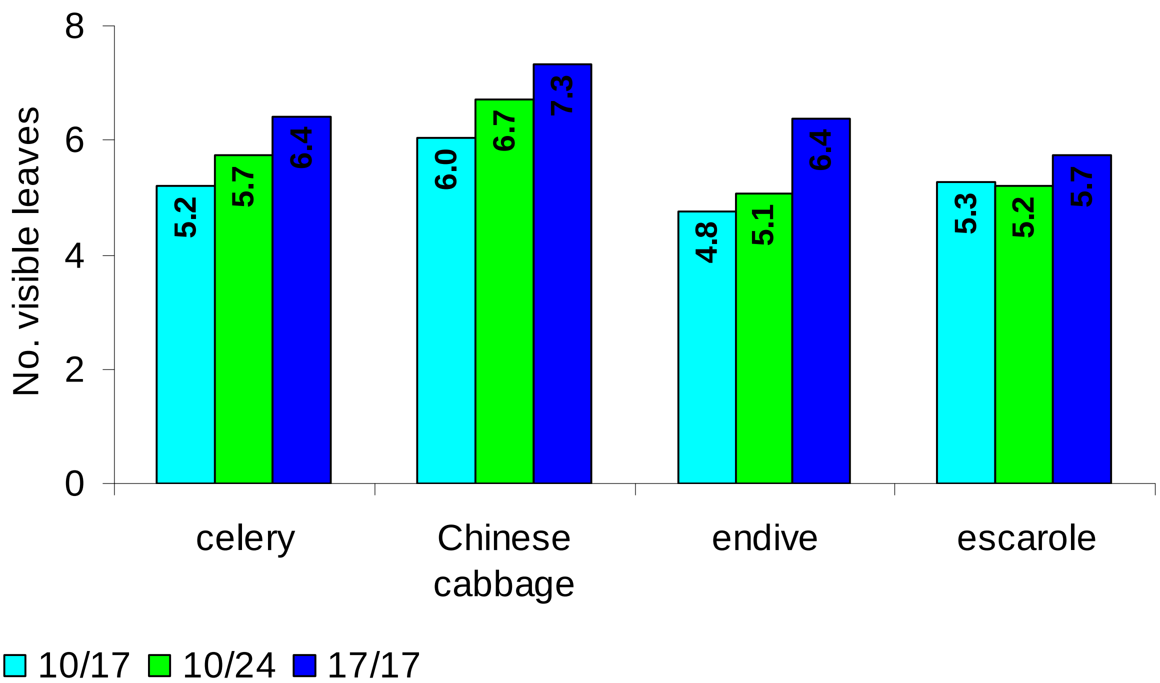

Figure 11. The influence of propagation temperature on visible leaf number of celery (l.s.d. P<0.05 = 0.15), Chinese cabbage (l.s.d. P<0.05 = 0.19), endive (l.s.d. P<0.05 = 0.20) and escarole (l.s.d. P<0.05 = 0.16) at the end of propagation

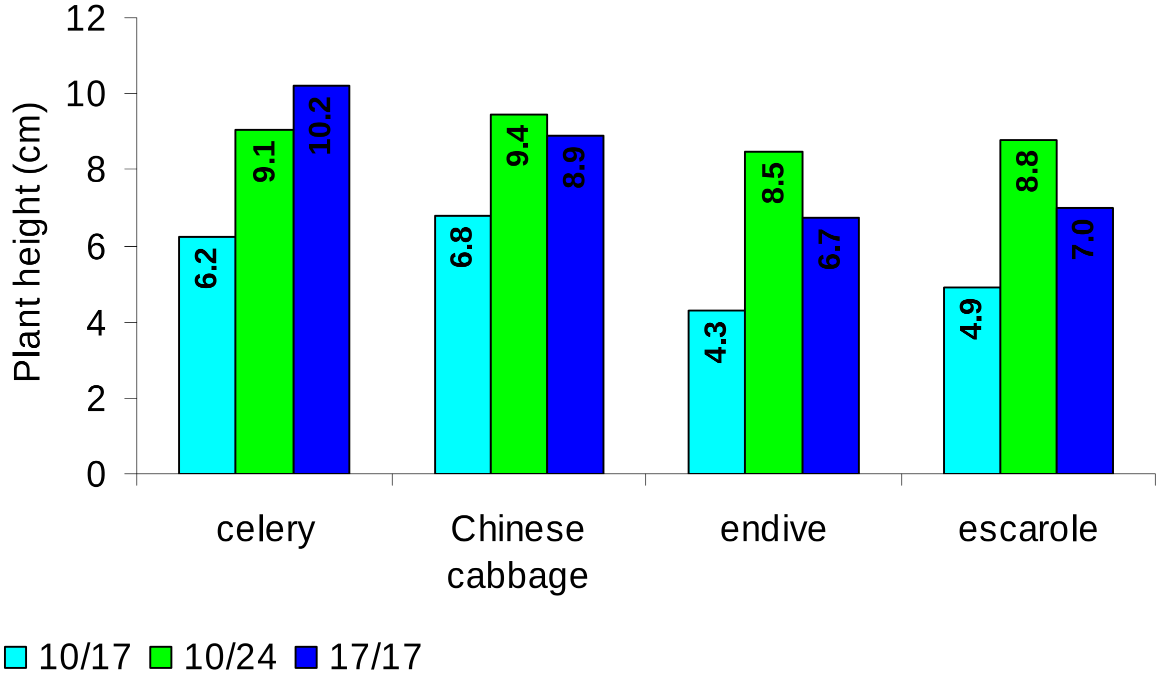

Figure 12. The influence of propagation temperature on plant height of celery (l.s.d. P<0.05 = 0.23), Chinese cabbage (l.s.d. P<0.05 = 0.21), endive (l.s.d. P<0.05 = 0.18) and escarole (l.s.d. P<0.05 = 0.24) at the end of propagation

Plant size x propagation temperature interaction

There was a significant (P<0.05) interaction between plant size and propagation temperature for endive, escarole and Chinese cabbage (figures 13-15). In general propagation temperature had the greatest impact on transplants given the longest time in propagation and therefore grown to a larger size. Parameters influenced varied with species. Shoot fresh weight of the smallest transplants for example was not influenced by propagation temperature but there were significant (P<0.05) propagation temperature effects on the standard and large transplants. Higher propagation temperature increased leaf number all plant sizes of Chinese cabbage, celery and endive but for escarole there were no differences between smaller transplants whilst trends varied for the two larger transplant sizes. The extension growth relating to the 10/24 treatment compared with the 17/17 treatment occurred for all plant sizes of endive and escarole but did not occur in the smallest Chinese cabbage transplants.

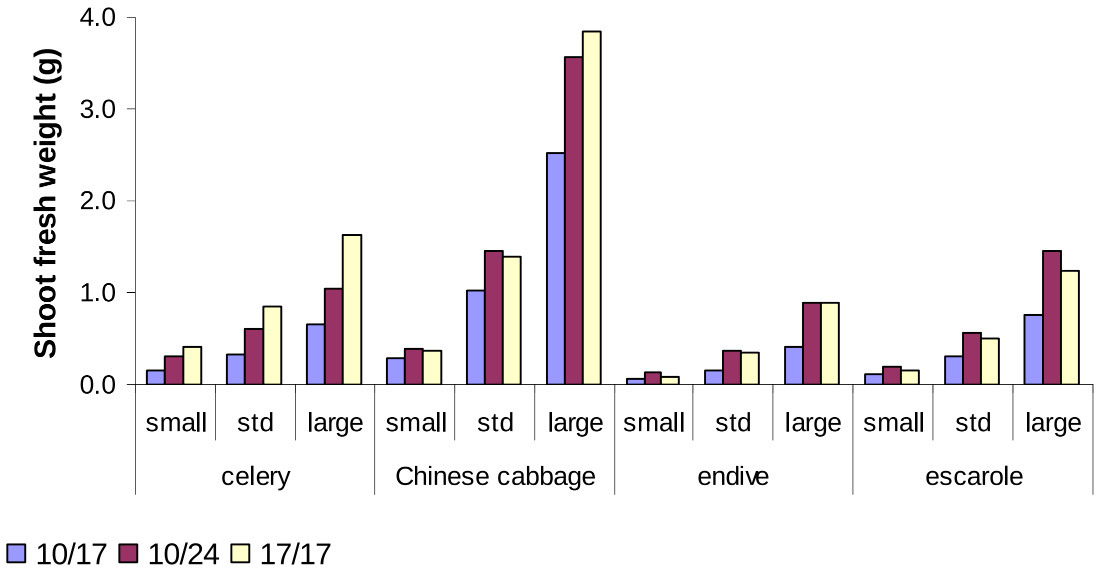

Figure 13. The interaction between propagation temperature and transplant size on shoot fresh weight of celery (l.s.d. P<0.05 = 0.07), Chinese cabbage (l.s.d. P<0.05 = 0.19), endive (l.s.d. P<0.05 = 0.05) and escarole (l.s.d. P<0.05 = 0.10) at the end of propagation

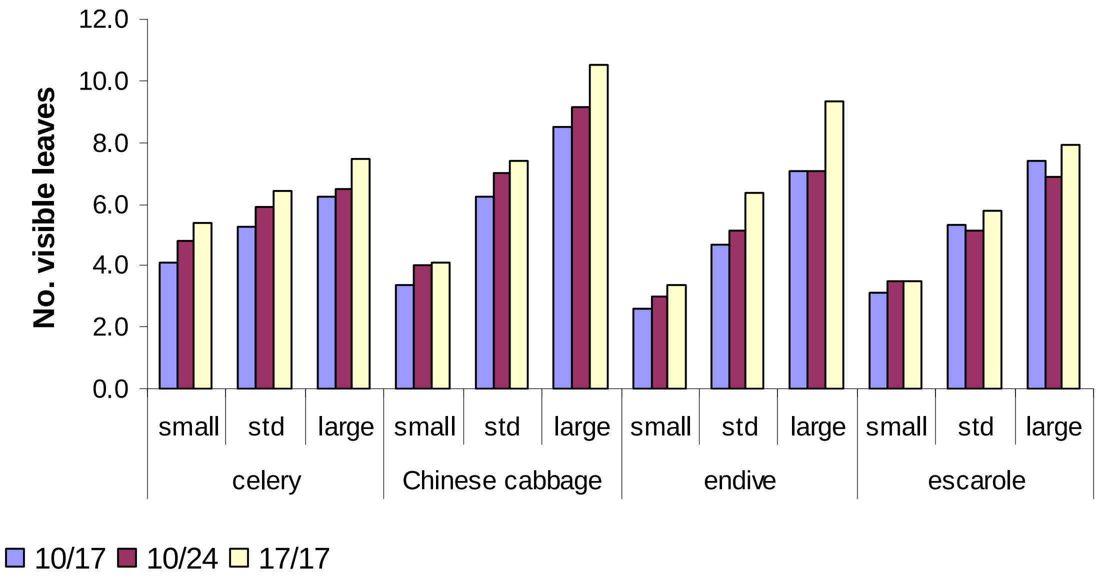

Figure 14. The interaction between propagation temperature and transplant size on visible leaf number of celery (l.s.d. P<0.05 = 0.25), Chinese cabbage (l.s.d. P<0.05 = 0.34), endive (l.s.d. P<0.05 = 0.35) and escarole (l.s.d. P<0.05 = 0.38) at the end of propagation

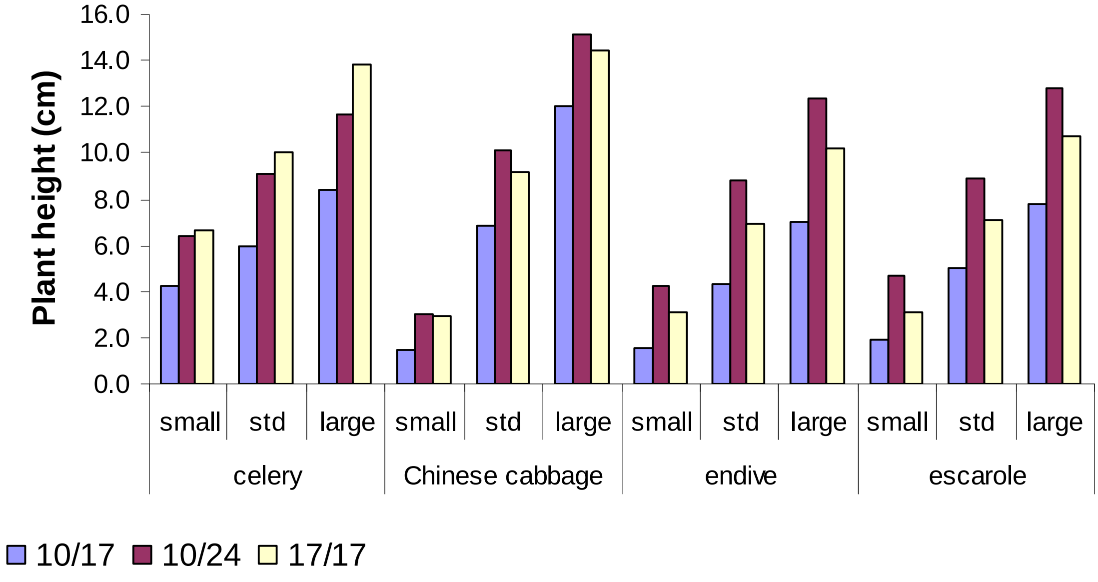

Figure 15. The interaction between propagation temperature and transplant size on visible plants height of celery (l.s.d. P<0.05 = 0.57), Chinese cabbage (l.s.d. P<0.05 = 0.36), endive (l.s.d. P<0.05 = 0.31) and escarole (l.s.d. P<0.05 = 0.42) at the end of propagation

Assessments at harvest stage

Apex length (assessed on celery and Chinese cabbage only)

Apex length data were assessed using an analysis of variance and differences which are separated by the relevant l.s.d. where P<0.05, are considered as being significant.

Apex length of celery and Chinese cabbage measured at harvest provides an indication of progression towards flowering when it is difficult to make this assessment on external appearance alone.

Average apex length was smallest for plantings later in the season (figure 16) and therefore at higher temperature post planting.

The cold shock treatment increased apex length of the wk 10(cs) plants in comparison with the wk 11 plants of both species and also of the wk 14(cs) Chinese cabbage plants compared with wk 15. The cold shock treatment was therefore effective at increasing bolting of plants transplanted into the field at the same time as plants given a conventional weaning treatment in order to evaluate the risk of treatments applied as comprehensively as possible.

From the data collected later in the season where no bolting was recorded for these two species, it is estimated that apex lengths (base plate to tip of apex) of around 8-9cm for Chinese cabbage and 13 cm in celery are 'baseline' figures and that plants can be assumed to have progressed towards bolting if apex length exceeds these figures. The greater the increase in apex length above these baseline figures, the greater the progression towards flowering (and hence the greater the risk of bolting).

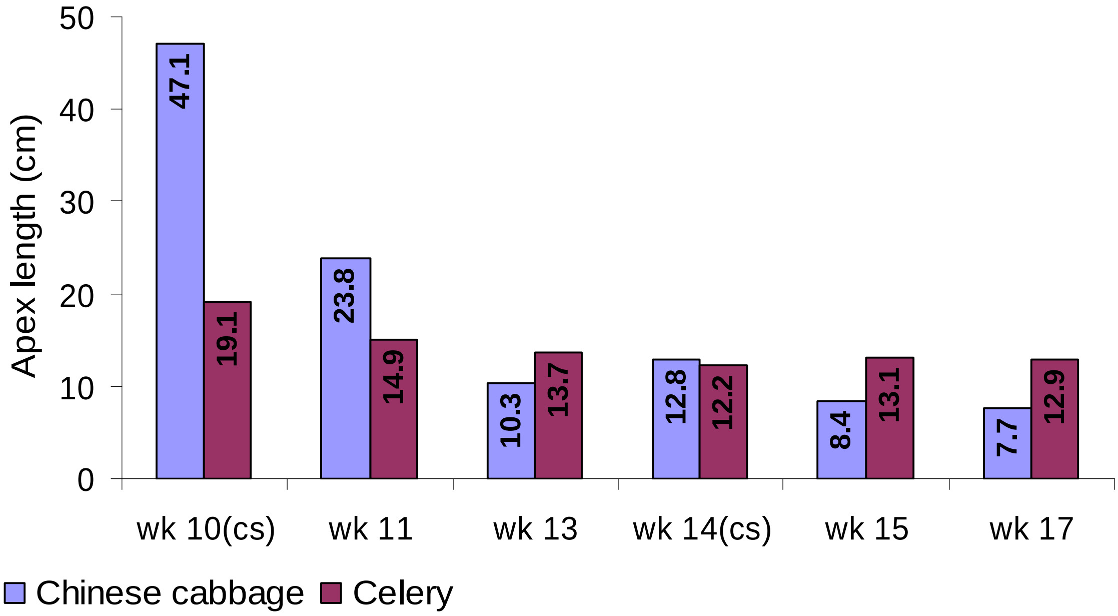

Figure 16. The influence of planting time (batch) on apex length at harvest of celery (l.s.d. $P<0.05$ = 1.20) and Chinese cabbage (l.s.d. $P<0.05$ = 1.22)

Large transplants had significantly ($P<0.05$) greater apex length at harvest than small transplants for the wk 10(cs) and wk 11 batches of both species and also for the wk 14(cs) batch of Chinese cabbage (figure 17). Commercially raised plants had shorter apices than treatment plants of both species from the earliest planting date, but this was also a cold shock treatment where weaned plants had a cold period prior to planting which was not imposed on the commercial plants. In general however apex length was comparable between experimental and commercial plants.

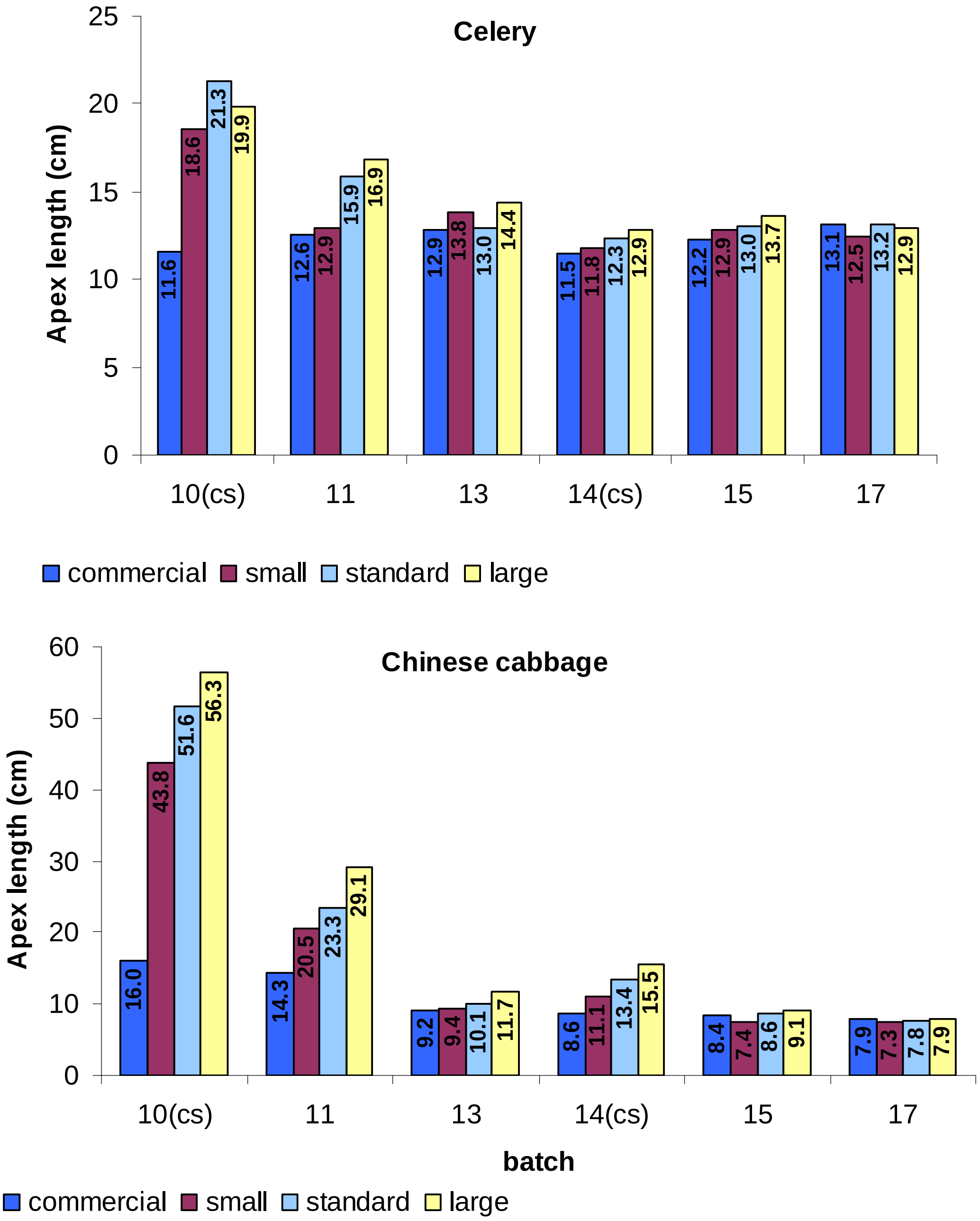

Figure 17. The influence of transplant size on apex length at harvest of celery (l.s.d. P<0.05 = 1.18) and Chinese cabbage (l.s.d. P<0.05 = 1.22) for 6 batches plants

Propagation temperature had a significant (P<0.05) influence over apex length at harvest of early plantings (wk 10(cs) and 11) of celery and Chinese cabbage and also the wk 14(cs) batch of Chinese cabbage. Plants propagated in the lowest temperature (10/17) were up to 9.8cm taller in apex length for celery and 25.2cm taller for Chinese cabbage compared with the two higher temperature treatments (figure 18). The 10/24 and 17/17 treatments produced plants with similar apex length at harvest overall, although the 17/17 treatment gave slightly greater apex length (up to 2.0cm for celery and 3.3cm for Chinese cabbage) than the 10/24 treatment where differences did occur.

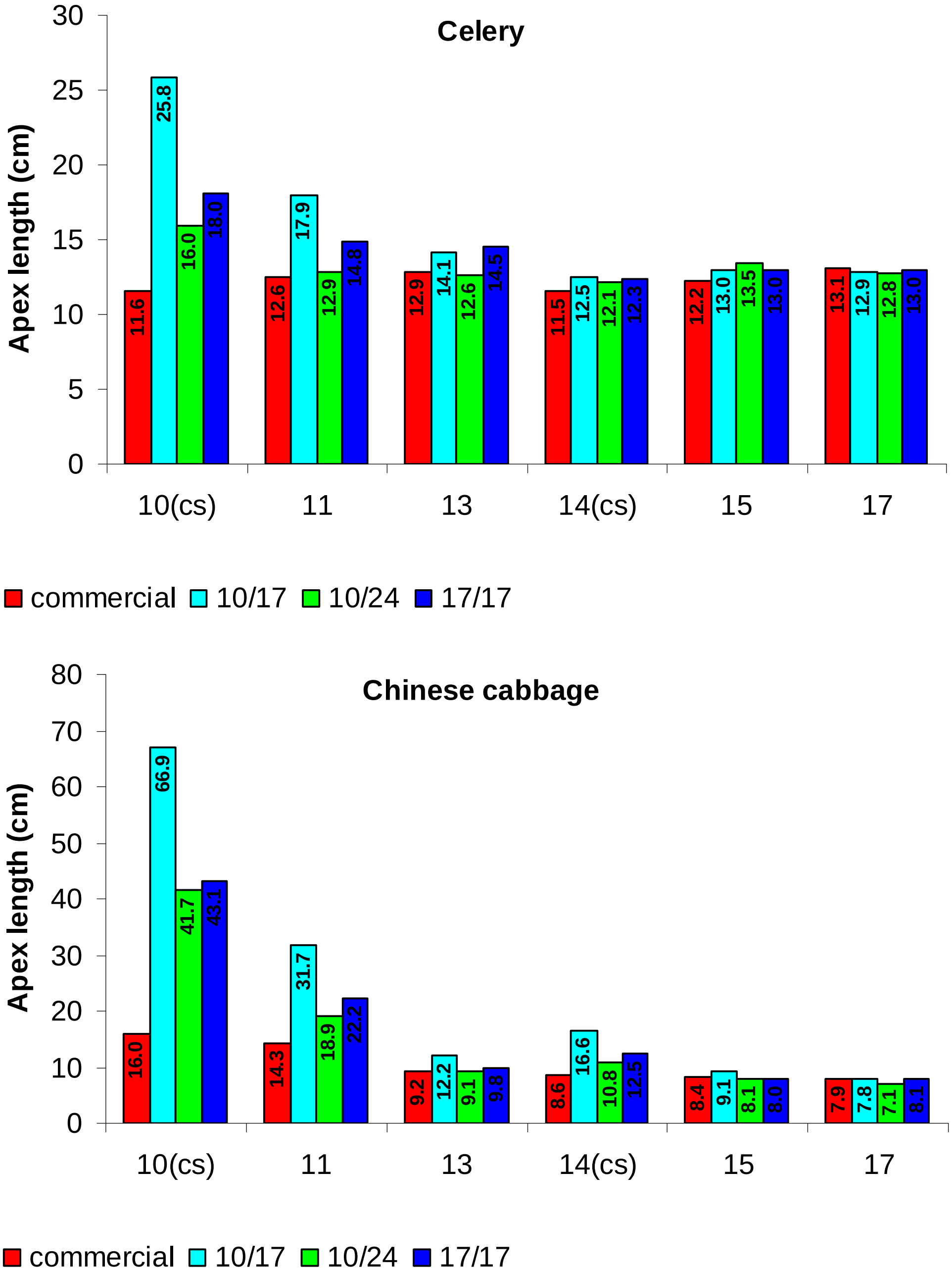

Figure 18. The influence of propagation temperature on apex length at harvest of celery (l.s.d. P<0.05 = 1.20) and Chinese cabbage (l.s.d. P<0.05 = 1.22) for 6 batches plants

Since production of different sizes of transplant for a set planting date required plants to be grown for different lengths of time, evaluating transplant size was complicated by the fact that environmental conditions experienced during propagation would vary. It was generally possible to hold glasshouse temperatures close to desired set points and so temperatures experienced whilst plants were receiving different treatments were comparable between plant sizes within the same batch e.g. average daily temperature experienced by the small Chinese cabbage transplants in the 17/17 compartment varied by only 0 to 0.13°C compared with the larger transplants within the same batch across the 6 sowing dates evaluated. However if means are weighted according to the length of time spent within each treatment (i.e. the sum of 24 hour temperature during propagation divided by time in propagation), the larger Chinese cabbage transplants experienced average temperatures around 1.1 to 1.5°C higher than the smallest transplants for the 17/17 temperature treatment during the propagation phase of growth overall; which is largely due to the extra time spent in the heat. These differences in weighted average temperature for propagation would be similar if plants were sown on a common date and weaned at different times, because the larger transplants would still benefit from a longer period in the heat, but transplants of different sizes would be exposed to greater variation in temperature during weaning given the more variable temperatures of the compartment set for frost protection only. Hence whilst staggering sowing date minimises the variation experienced by the three transplant sizes within the same batch of plants, small differences in achieved environment were experienced. There was therefore some overlap of sowing schedules built into the experiment to allow for comparisons between plants of a similar age but transplanted at different times (and hence sizes) into the field, to contrast with the staggered sowing and fixed weaning date approach used in 2008.

The two approaches to examining the influence of size of plant on progression towards flowering produced different results (figures 19 & 20), which was also found in year 1 experiments (2007). Where plants were sown at the same time and planted at different times, the smaller plants that were transplanted earlier had longer apex length at harvest than the larger plants which were transplanted later (figures 19&20 a-c). By contrast, where sowing was staggered and transplanting carried out at the same time, the larger transplants had greater apex length at harvest than the smaller transplants (figures 19&20 d-f). Whilst the staggered planting approach produced the more expected result (i.e. that smaller plants with fewer leaves would be more prone to bolting), the staggered sowing approach may more reliable because conditions from weaning onwards (when the greatest risk of bolting occurs) were identical for all plant size treatments. The staggered sowing approach would also be more representative of commercial production (i.e. where the grower would be calculating sowing schedules according to size of plant required and its target planting date).

These data also show that differences in transplant size were greater earlier in the season when conditions are more likely to promote bolting. Furthermore, differences in apex length between the small and large transplants at harvest were greater when plants had been propagated at the lower average temperature (10/17). For example for celery the differences between large and small transplants were only significant ($P<0.05$) for the first one or two batches of the plants propagated at higher temperature but were also significant for the third batch of plants raised in the 10/17 treatment. The differences in apex length at harvest between small and large transplants of celery were up to 7.6cm for plants raised at 10/17 and up to 4.0cm for plants raised at 10/24 or 17/17.

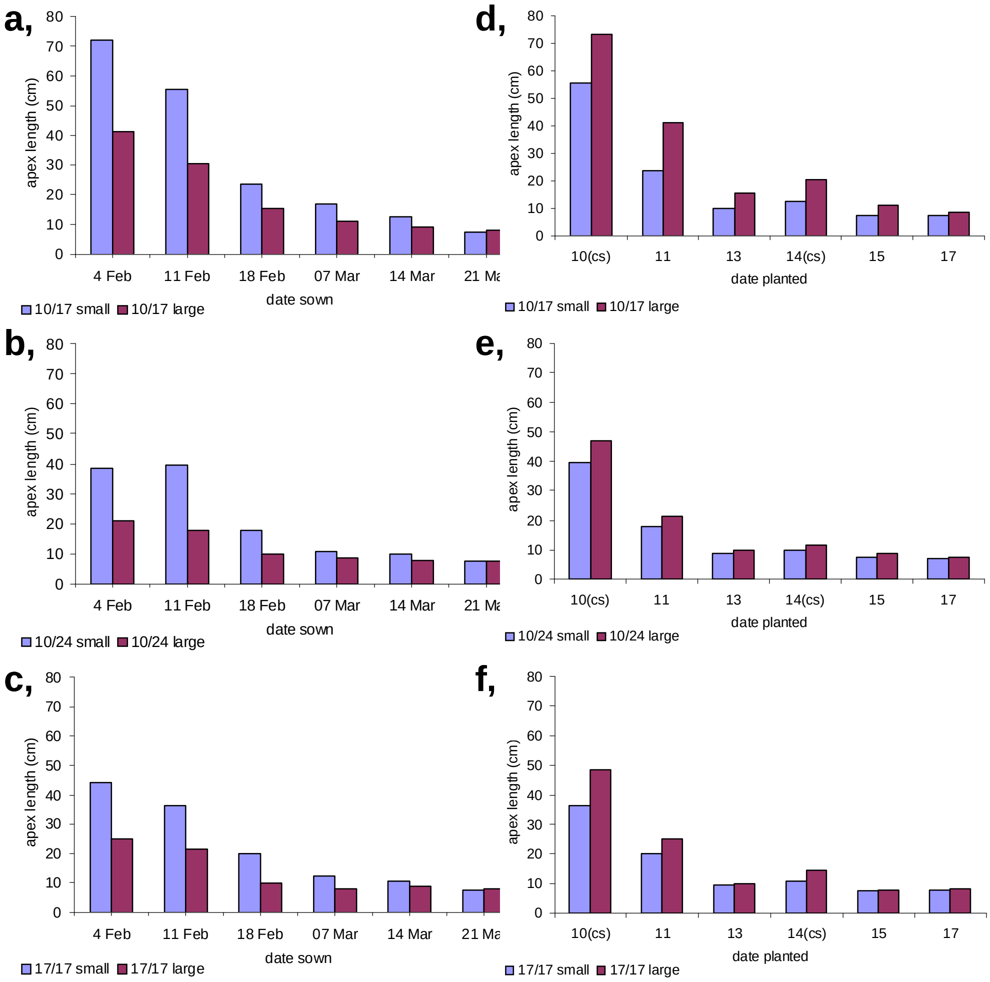

Figure 19. The influence of size of Chinese cabbage transplants on apex length at harvest where plants are either sown at the same time and planted out at different times (a–c) or sown at different times and planted out at the same time (d-f), for three temperature regimes

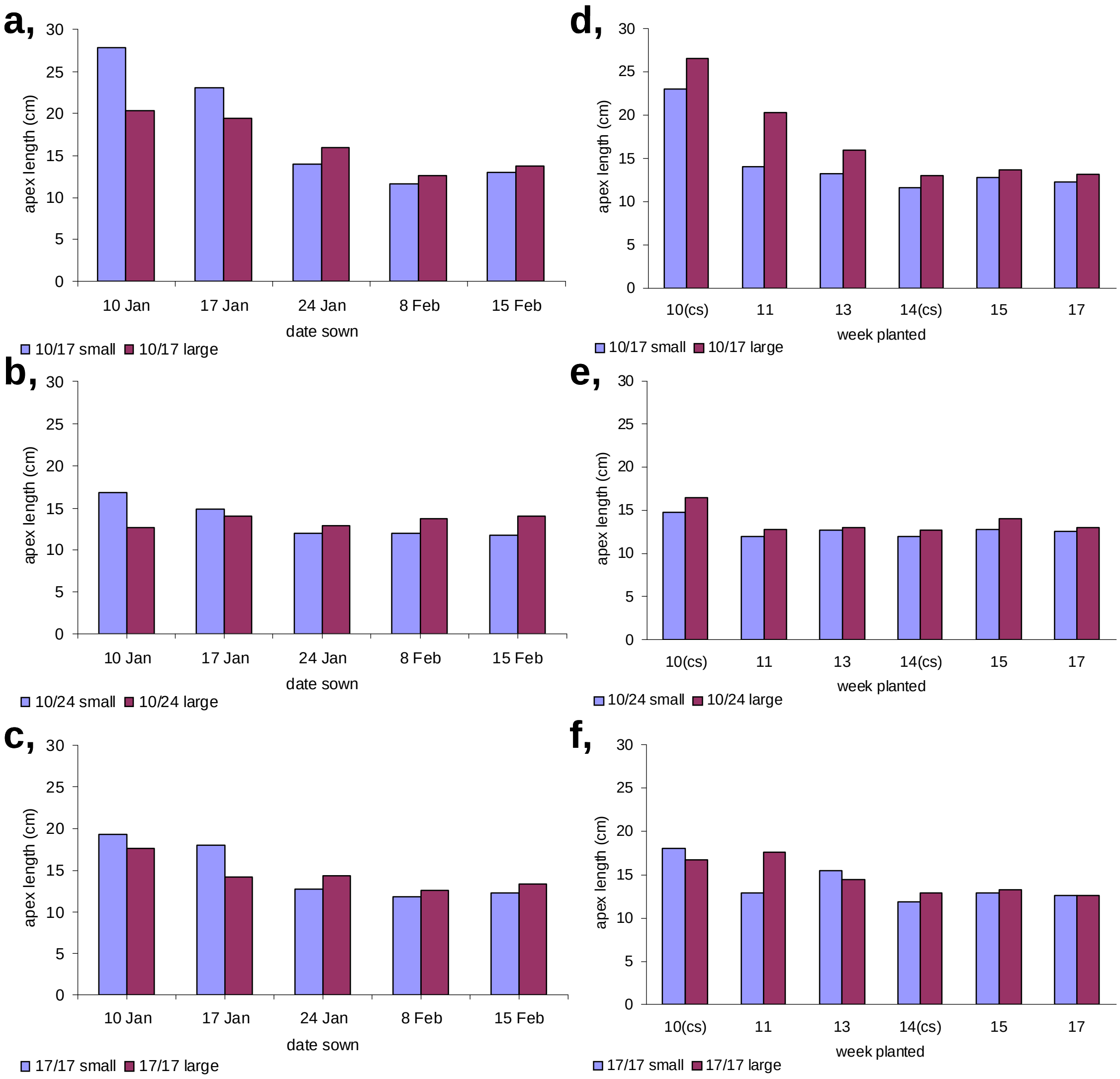

Figure 20. The influence of size of celery transplants on apex length at harvest where plants are either sown at the same time and planted out at different times (a–c) or sown at different times and planted out at the same time (d-f), for three temperature regimes

Bolting

An accumulated analysis of deviance was carried out on bolting data following a binomial transformation and since this approach generated l.s.d. values for each set of data point comparisons, it is not practical to quote all the relevant l.s.d values, instead, the text indicates where comparisons are separated by differences greater than the appropriate l.s.d. Furthermore it was not possible to create a balanced analysis if the commercial plants were included along with the 3 x 3 factors of transplant size and propagation temperature; hence values for the commercial plants were not included in the formal analysis, and while data for commercial plants has been included in the graphs below for all species for reference purposes, they cannot be formally compared against the main experimental treatments using calculated l.s.d. values.

There was significantly ($P<0.05$) more bolting in earlier than later batches of plants (figure 21). The cold shock treatment significantly increased ($P<0.05$) bolting of week 10 plants compared with week 11 in all species as well as in week 14 compared with week 15 of endive and escarole. Endive had the highest levels of bolting overall and bolting was recorded in batches planted up to week 17. Escarole also had high levels of bolting which occurred up to the week 15 batch. Celery had the lowest levels of bolting overall with no bolting recorded beyond the batch planted in week 11.

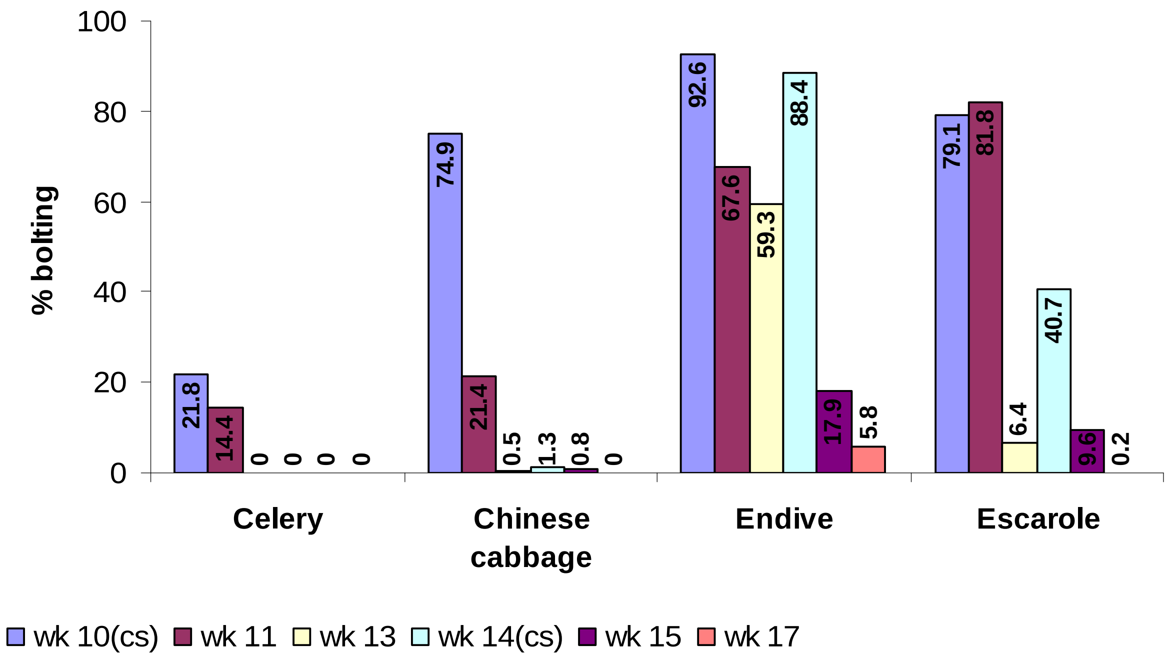

Figure 21. The influence of planting time (batch) on % bolting at harvest of celery, Chinese cabbage, endive and escarole

Accurate visible detection of bolting for celery plants in situ is constrained until the flowering stem appears in the centre of the plant. Records of bolting were therefore taken as number of plants apparently extending as well as number of plants with visible flowers. Whilst the latter record was more accurate, the former gives a closer approximation to the bolting records taken for the other species assessed where extension growth is a clearer indication of bolting. The percentage of celery plants apparently extending at harvest stage significantly ($P<0.05$) increased as the size of transplant increased (figure 22) for the first two batches planted. Commercial plants had comparable levels of bolting to the treatment plants.

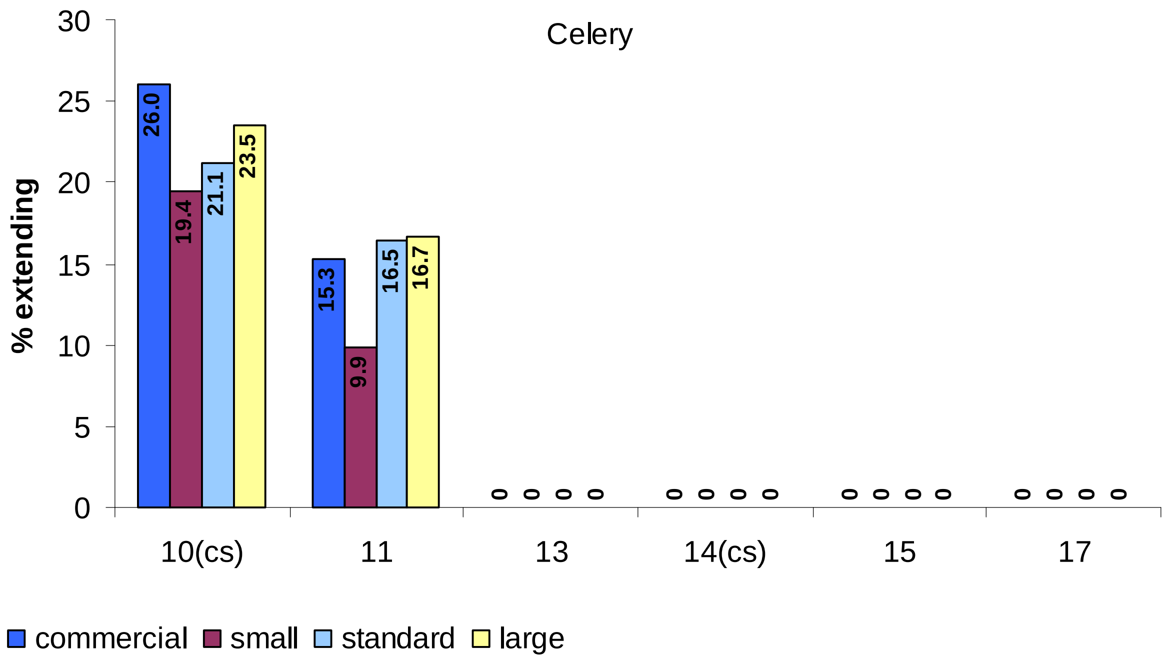

Figure 22. The influence of transplant plant size on % plants extending at harvest

Since expression of bolting precedes that of flowering, there were fewer plants flowering than showing signs of extension. The flowering data shows similar trends for experimental plants where larger transplants produced significantly ($P<0.05$) more flowering plants at harvest than smaller transplants in the wk 10 batch but differences were too small to be significant in the week 11 batch. There are discrepancies for the commercial celery plants (figure 23) however which had the highest level of plants extending but the lowest levels (0) of plants flowering from the week 10(cs) batch of plants. Both types of record are difficult to assess eternally for celery, flowers may for example be obscured within the heart of the plant. However the apex length data described previously is more clear cut and suggests bolting in the commercial celery was lower in the week 10(cs) batch than from the experimental plants that had been subjected to an extra period of cold.

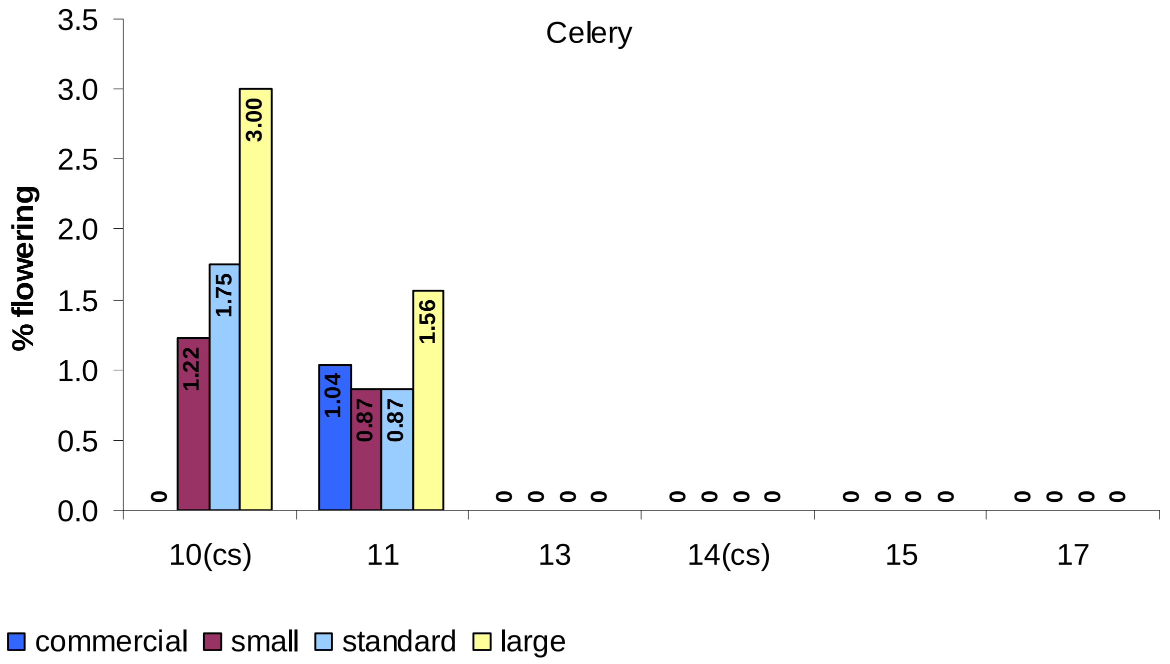

Figure 23. The influence of transplant plant size on % plants flowering at harvest

Larger transplants also produced significantly (P<0.05) higher levels of bolting than smaller transplants of the week 10 and week 11 batches of Chinese cabbage (figure 24).

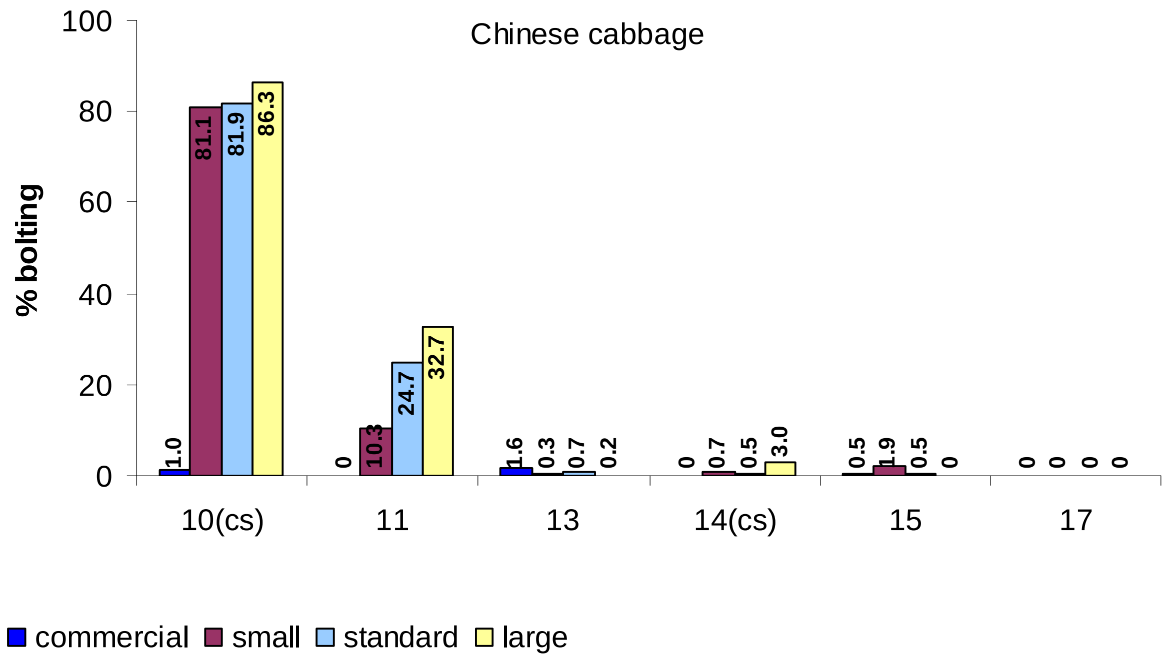

Figure 24. The influence of transplant plant size on % plants bolting at harvest

Large endive transplants also had significantly (P<0.05) more bolting than smaller ones (figure 25) in the week 11, 13, 15 and 17 batches. Where there were very high levels of bolting (batches planted in week 10 and 14 following the cold shock treatment), transplant size had no significant effect. The effectiveness of the cold shock treatment is clear from data for the wk14 batch of plants where commercial plants had no bolting whilst experimental plants had 96.0 to 99.7% bolting. There was less difference between commercial and experimental plants in the first batch planted when external temperatures were apparently sufficient to induce high levels of bolting without the need for the cold shock treatment.

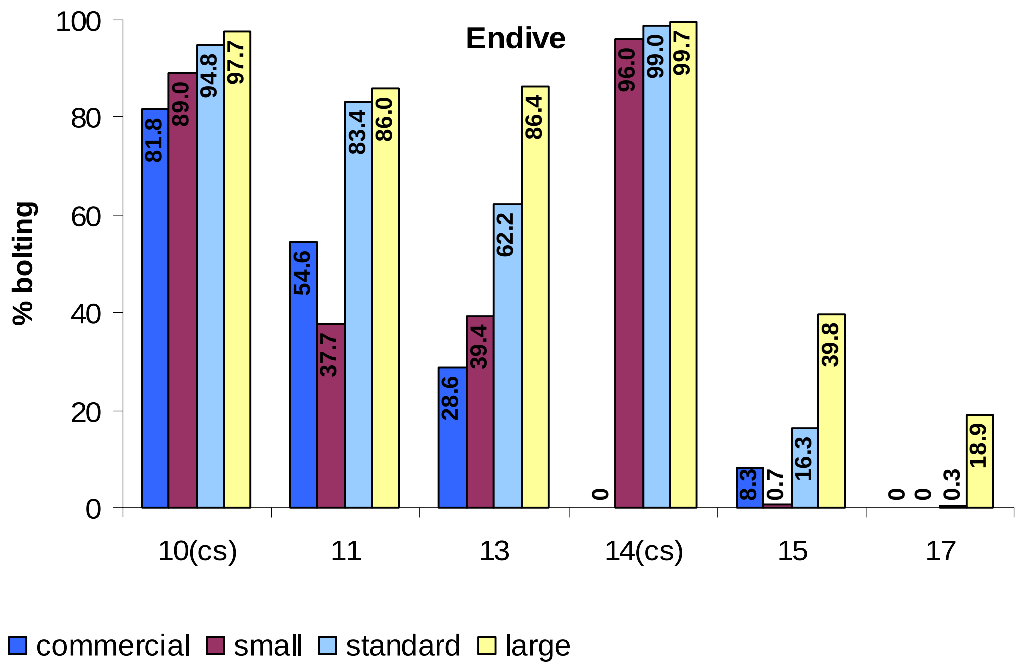

Figure 25. The influence of transplant plant size on % of endive plants bolting at harvest

Where weaned plants were subjected to the cold shock treatment (week 10 and 14), the smallest escarole transplants had significantly (P<0.05) less bolting than the standard and large sized transplants (figure 26). For the week 13 and 15 batches of plants where there was less bolting recorded overall, the largest transplant size produced significantly (P<0.05) more bolting than both the small and standard sizes.

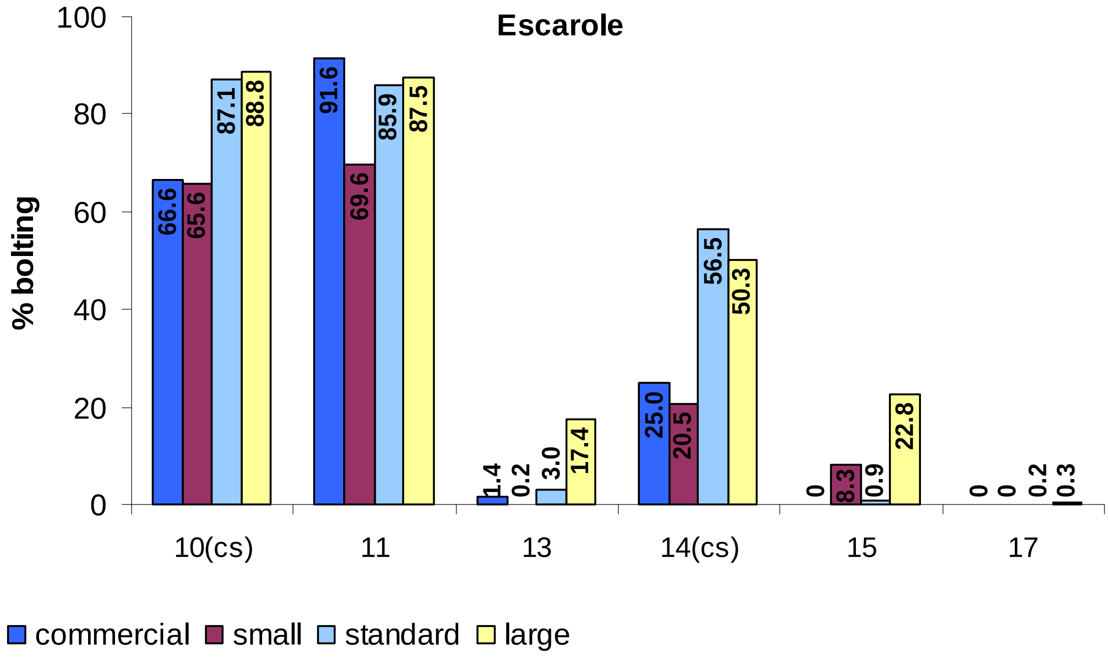

Figure 26. The influence of transplant plant size on % of escarole plants bolting at harvest

Lower propagation temperature (10/17) produced significantly (P<0.05) more celery plants extending at harvest than the higher temperatures (10/24 and 17/17) for the week 10 batch of plants that were given the extra challenge of the cold shock treatment prior to planting (figure 27). There were no significant differences between propagation temperature treatment for the second batch of plants and no further incidence of extending plants in later planted batches.

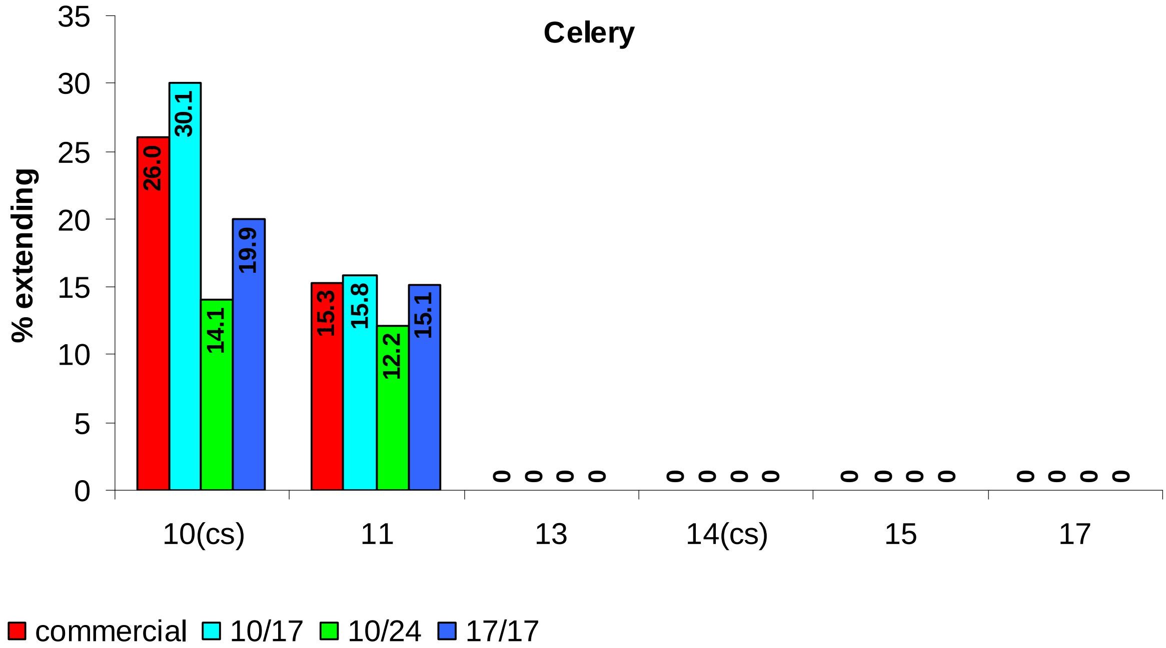

Figure 27. The influence of propagation temperature on % of celery plants extending at harvest

As noted previously, there were fewer plants flowering than showing signs of extending or bolting (figure 28). As with the data for % extending, lower propagation temperature (10/17) significantly (P<0.05) increased the percentage of plants flowering compared with higher temperatures (10/24 and 17/17) in batches planted in week 10 and 11.

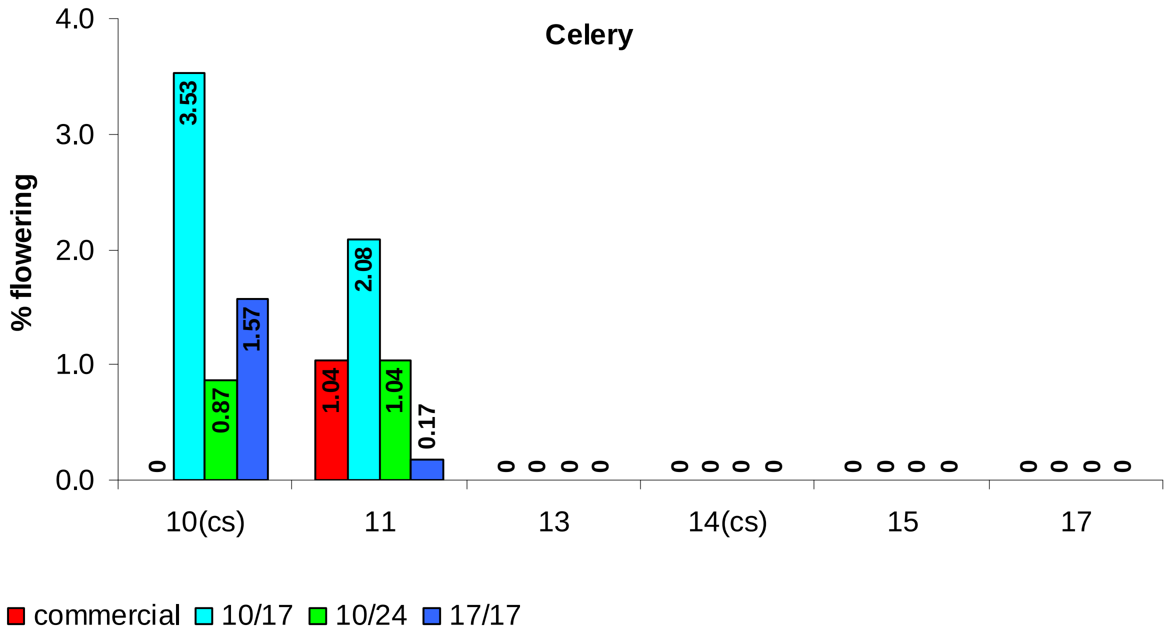

Figure 28. The influence of propagation temperature on % of celery plants flowering at harvest

Low (10/17) propagation temperature significantly (P<0.05) increased bolting compared with higher temperatures (10/24 and 17/17) for the week 10(cs) and week 11 batches of Chinese cabbage (figure 29). For the week 10(cs) batch of plants, the 17/17 treatment also produced significantly (P<0.05) higher levels of bolting than the 10/24 treatment despite these treatments giving comparable mean 24 hour temperature in propagation.

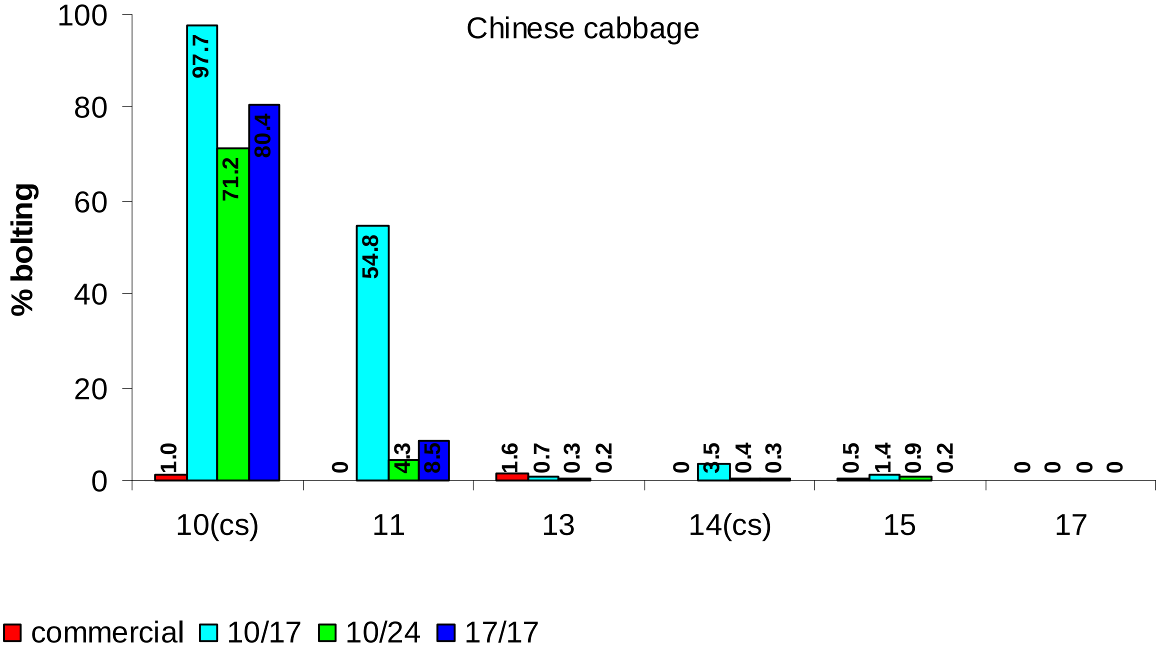

Figure 29. The influence of propagation temperature on % of Chinese cabbage plants bolting at harvest

There were high levels of bolting in endive plants from all temperature treatments following planting in week 10(cs), 11 and 14(cs) (figure 30) where either low external temperatures promoted bolting (week 10(cs) and week 11) or where the cold shock treatment apparently increased the incidence of bolting (batch 14(cs) where there were no commercial plants bolting). In the week 13, 15 and 17 batches, the lowest propagation temperature produced significantly ($P<0.05$) more bolting than higher propagation temperature. There was also more bolting from the 17/17 treatment than from the 10/24 treatment in the week 13 batch of plants.

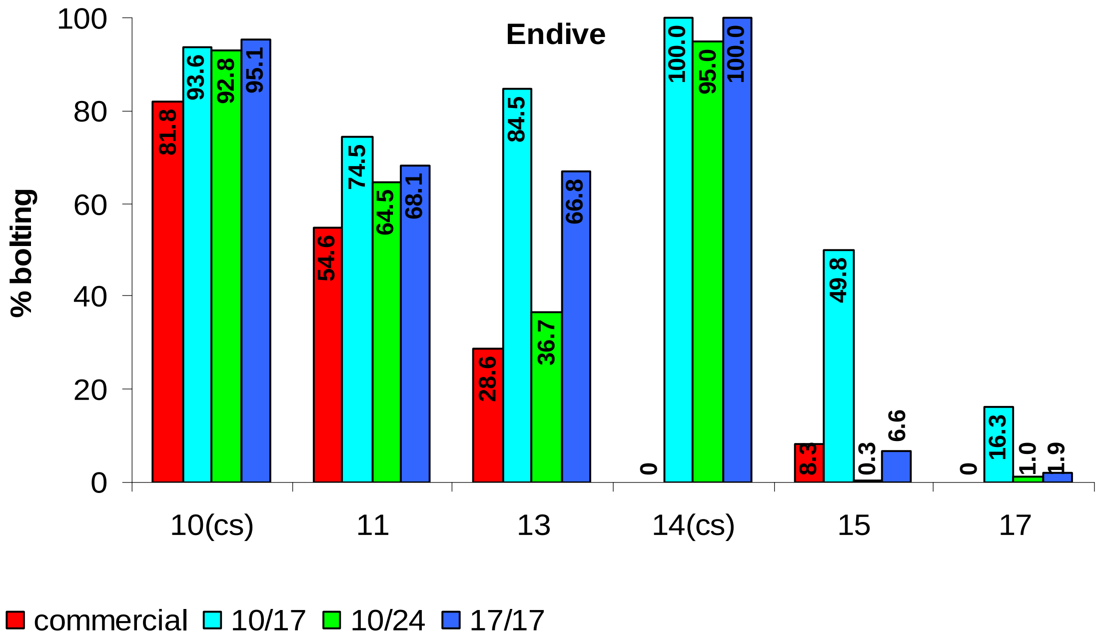

Figure 30. The influence of propagation temperature on % of endive plants bolting at harvest

As with endive, all treatments resulted in high levels of bolting in escarole in the week 10(cs) and 11 batches with no significant differences between propagation temperature treatments (figure 31). In week 13, 14(cs) and 15 batches however, the lowest propagation temperature resulted in significantly more bolting than the higher temperatures. In the week 14 batch, where the cold shock treatment had been imposed, propagation in the 17/17 treatment also resulted in more bolting than the 10/24 treatment.

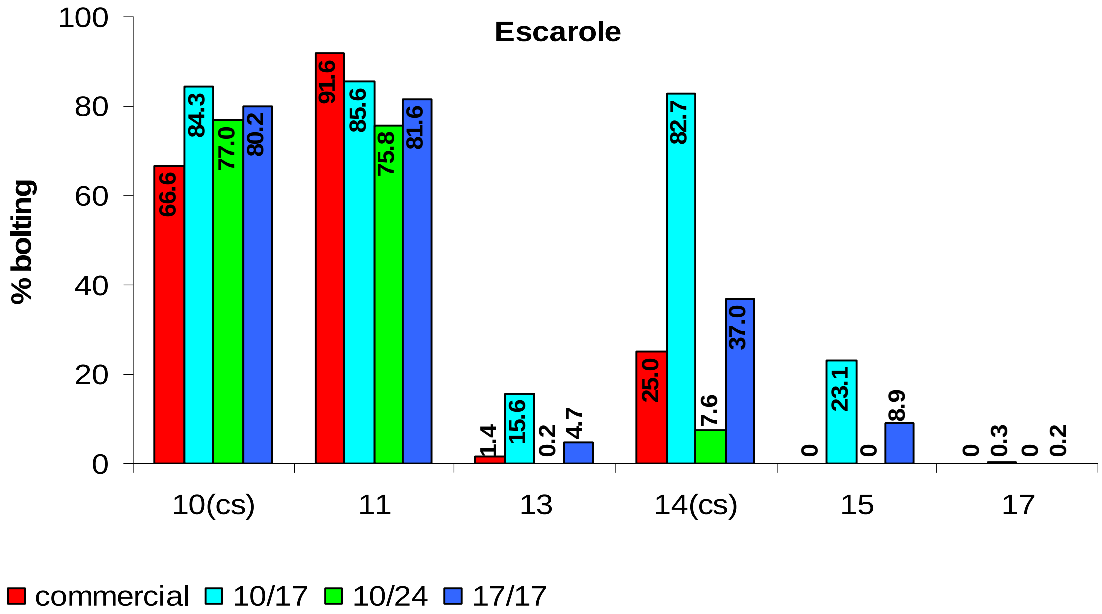

Figure 31. The influence of propagation temperature on % of escarole plants bolting at harvest

Head weight at harvest

Head weight data were assessed using an analysis of variance and differences which are separated by the relevant l.s.d. where $P<0.05$, are considered as being significant.

Average head weight varied with planting week throughout the season (figure 32). The most notable difference is for the low average weight of plants from the final batch of endive and escarole harvested which was only 50% or less than that of the next lowest head weight. Whilst commercial pressures govern the timing of harvest it would have been preferable for experimental purposes to harvest this final batch of plants later and therefore at a head weight closer to that achieved earlier in the season.

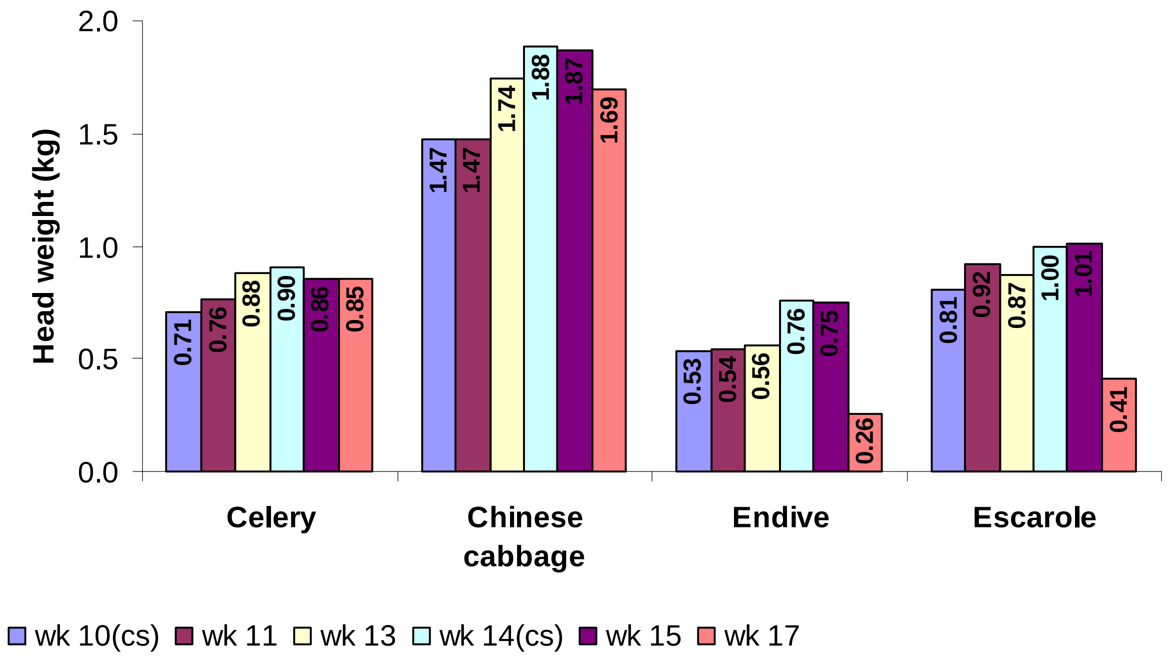

Figure 32. The influence of planting/harvesting date on head weight of celery, Chinese cabbage, endive and escarole

Size of transplant influenced celery head weight at harvest (figure 33) with larger transplants being significantly ($P<0.05$) heavier than the smaller transplants within batches planted in week 14 and 17. For earlier batches however where transplant size had been found to have a significant influence over apex length, there were no significant differences between head weights of different sizes of transplants. The head weights of commercial celery plants were generally comparable with experimental plants.

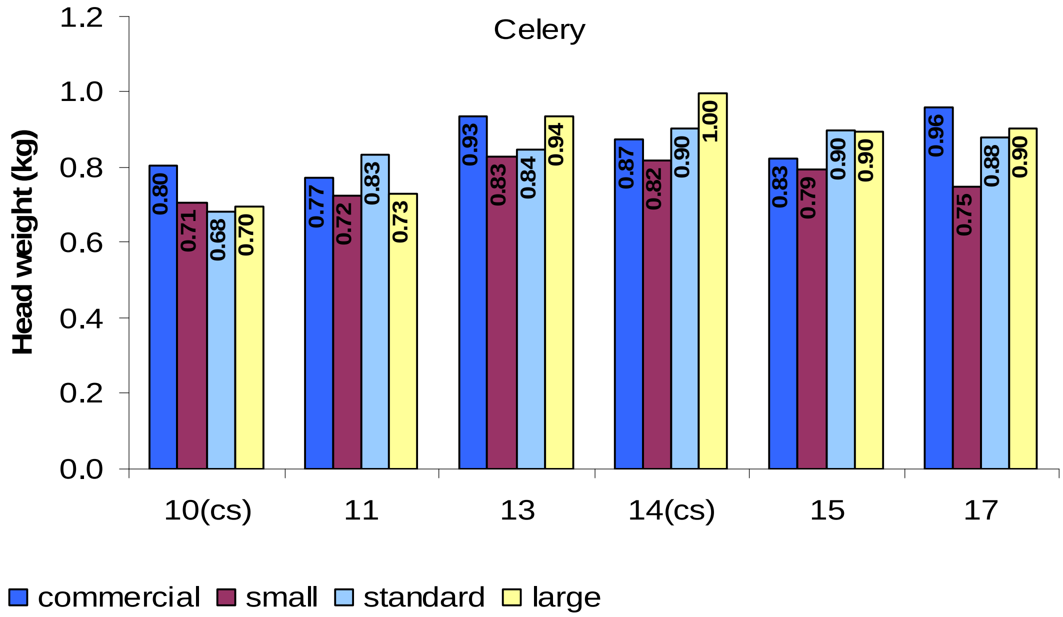

Figure 33. The influence of celery transplant size on head weight at harvest (l.s.d. $P<0.05$ = 0.13).

Transplant size had no significant influence over head weight of Chinese cabbage at harvest.

Small transplants produced significantly ($P<0.05$) less head weight at harvest than large transplants for batches of endive planted in week 11, 13, 15 and 17 (figure 34) which coincides with batches of plants in which transplant size had a significant influence on bolting. Hence where small transplants had lower levels of bolting they also had lower head weight. This suggests the smaller transplants would require a longer time in the field to achieve weight specification which risks increasing the levels of bolting expressed.

The head weights of commercial endive plants were generally comparable with experimental plants.

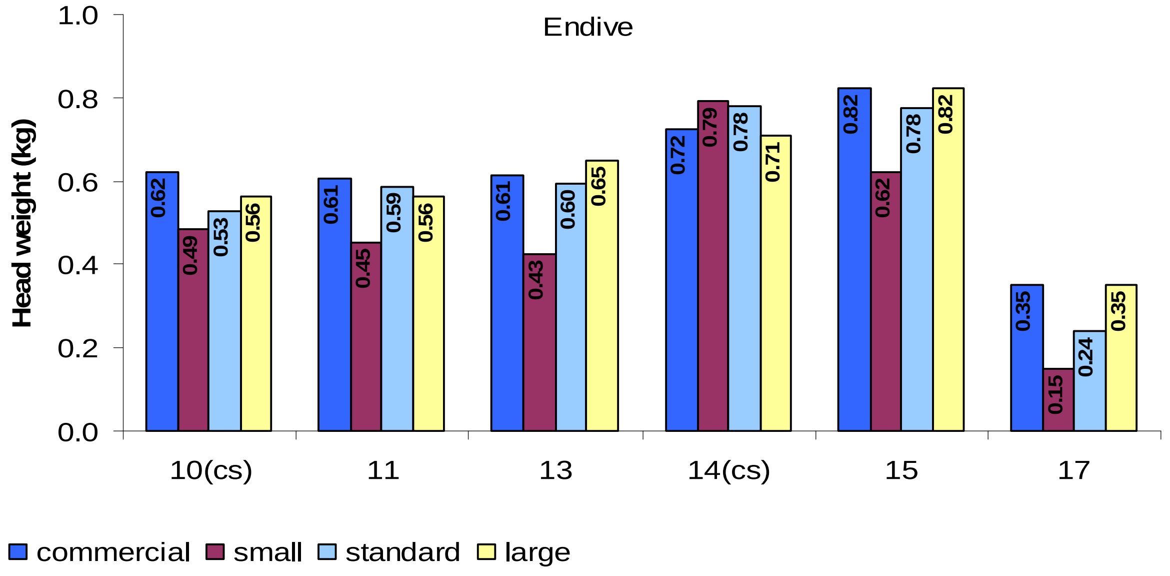

Figure 34. The influence of endive transplant size on head weight at harvest (l.s.d. P<0.05 = 0.099)

Larger escarole transplants had significantly (P<0.05) greater head weight than smaller transplants for batches planted in weeks 13, 15 and 17 (figure 35). There was also more bolting associated with larger transplants from planting in weeks 13 and 14 which again suggests that either smaller transplants would need a longer period in the field to produce equivalent weight to the larger transplants or that the larger transplants could be harvested sooner with potentially less bolting. However in the week 14(cs) batch, standard transplants produced higher head weight than large transplants. Commercial transplants had greater head weight than experimental plants in the week 10(cs) and 11 plantings but otherwise commercial plants were comparable with experimental ones.

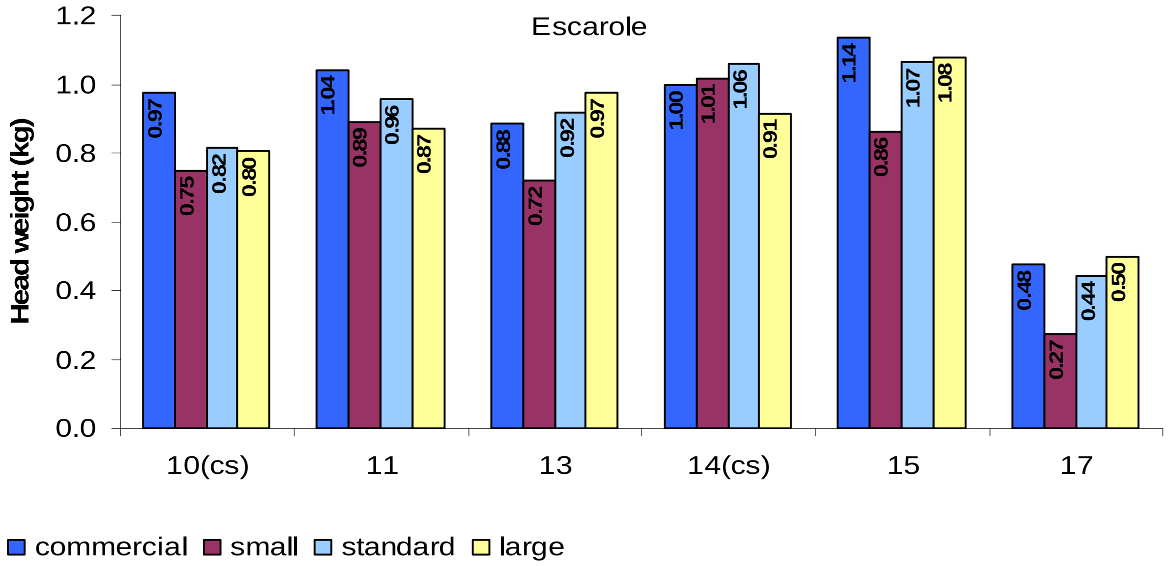

Figure 35. The influence of escarole transplant size on head weight at harvest (l.s.d. P<0.05 = 0.131)

Head weights of the commercial celery plants were similar to the 17/17 treatment throughout the experiment with no trends to indicate that the commercial plants were either consistently lighter or heavier than the experimental plants (figure 36). Where there were significant differences in head weight due to propagation temperature (i.e. in batches 10(cs), 13, 14(cs), 15, 17) the 10/17 and 10/24 treatments generally had smaller head weight than the 17/17 treatment.

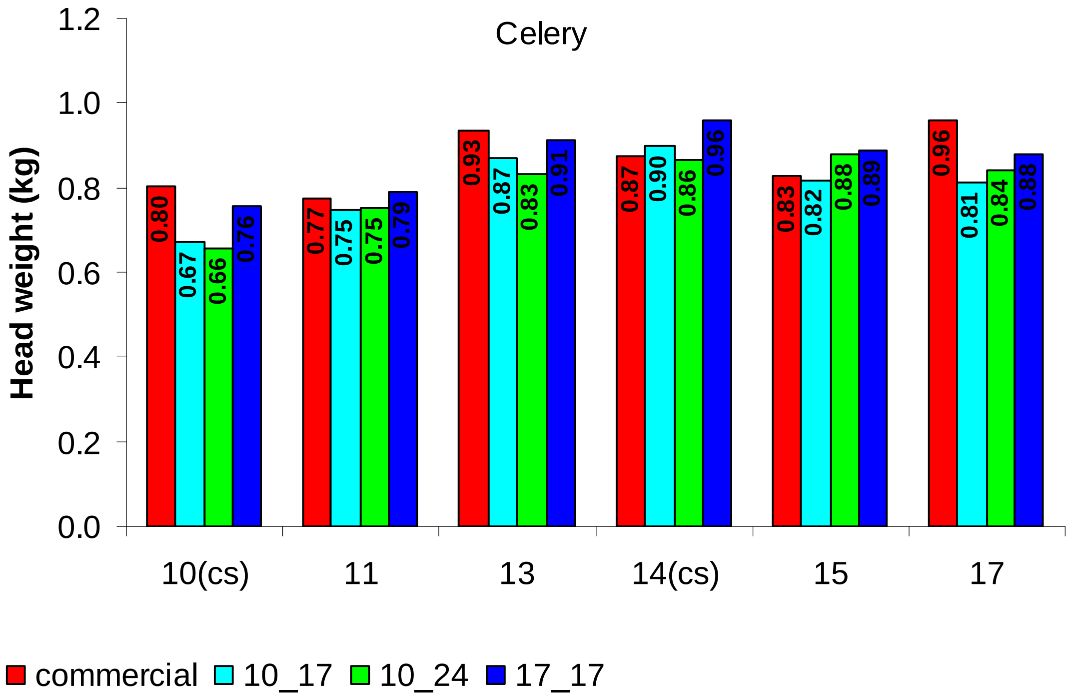

Figure 36. The influence of propagation temperature on celery head weight at harvest (l.s.d. P<0.05 = 0.042)

Propagation temperature had no significant influence over head weight of Chinese cabbage.

The effects of propagation temperature on endive head weight varied with batch. That is in the batches planted in weeks 10(cs), 11 and 14(cs); i.e. the batches with the highest levels of bolting, the 10/17 treatment produced lower head weight than the 10/24 or 17/17 treatments (figure 37). Differences relating to propagation temperature were not consistent for the other batches planted. Head weight of commercial plants was higher than for experimental plants in batches 10(cs), 11, 15 and 17.

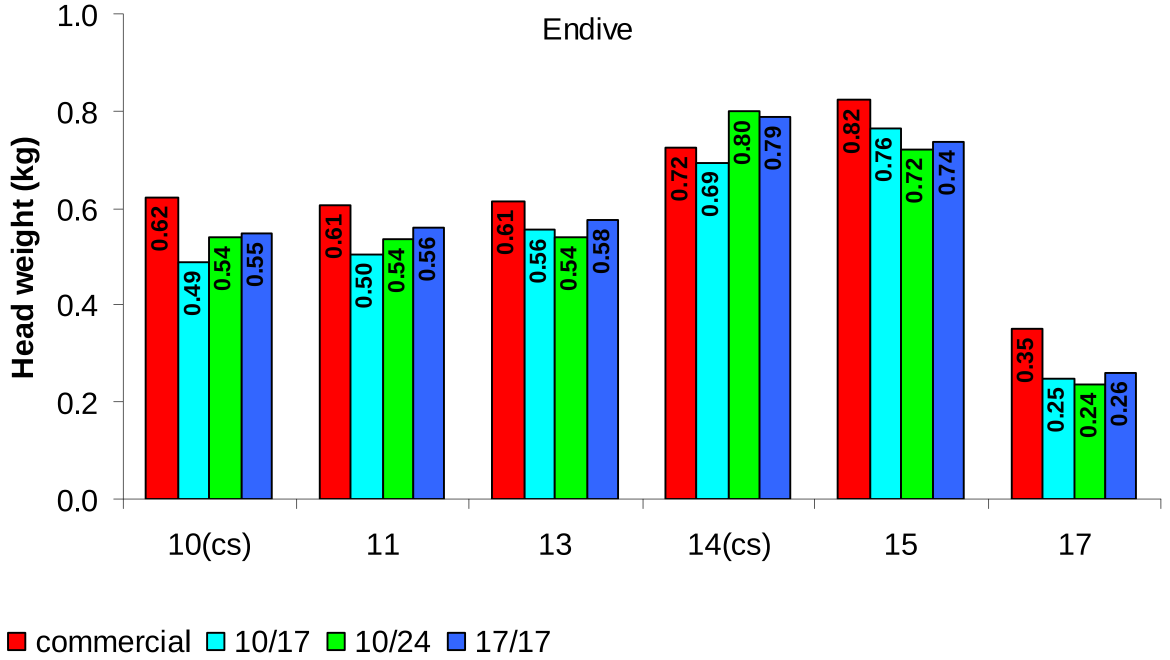

Figure 37. The influence of propagation temperature on endive head weight at harvest (l.s.d. P<0.05 = 0.034)

Propagation temperature had no significant influence over escarole head weight at harvest. Commercial plants were significantly heavier than experimental plants planted in week 10(cs) and 11 (figure 38).

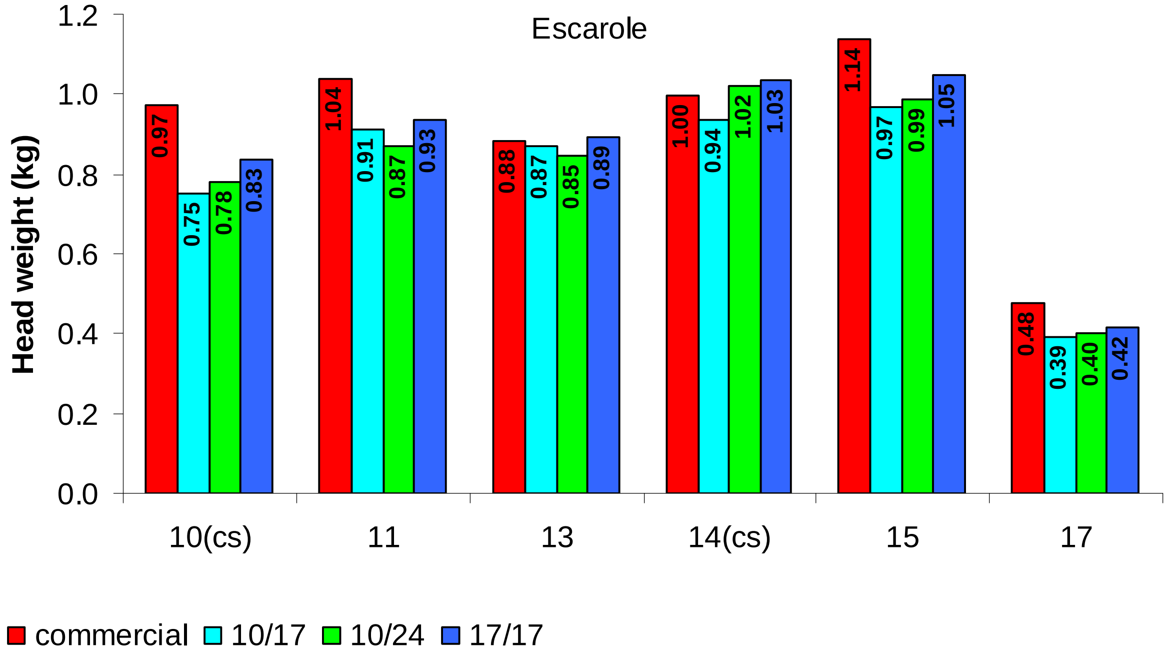

Figure 38. The influence of propagation temperature on escarole head weight at harvest (l.s.d. P<0.05 = 0.107)

Discussion

Both propagation temperature and transplant size significantly influenced transplants at the weaning stage. Schedules designed to vary size of transplant at weaning stage were successful in creating differences in shoot weight, height and leaf number. The extra 7 days of growth for the large transplants made a greater difference to transplant size in relation to the standard treatment for later batches of plants compared with earlier batches. By setting schedules which vary transplant size by staggering sowing dates, weaning then occurs on a pre-determined date across all treatments which leaves no flexibility for transferring plants early because they have reached the desired size early. Schedules in 2009 have been designed to take these differences in to account in order to standardise the size of the small, standard and large transplants from batch to batch. The 2009 schedule is also designed to reduce the size of the standard and larger transplants. The planned schedule will follow the 2008 sowing schedule of the small transplants with the standard plants sown 5 days later and the large transplants 10 days later in the first batch (week 11 planting). Since the number of days in heat decreases for later batches of plants sown, to allow for the more vigorous rate of growth, this 5 day gap will also decrease in later batches.

Propagating plants in a 10°C night / 17°C day temperature regime (achieving an average of around 14°C) produced smaller transplants at weaning stage when given the same amount of time in propagation as transplants grown at higher average temperature. Hence lowering propagation temperature to reduce energy inputs is likely to result in slower throughput which could negate energy savings on a batch basis. The impact of lower temperature on bolting at harvest must also be considered (see below). An average propagation temperature of around 17.5°C produced larger transplants whether this average was achieved with a constant 17°C regime day and night or with a variable regime with heat set at 10°C at night combined with a high (around 24°C) day set point to raise 24 hour average to the same level as the constant 17°C regime. All species had a higher visible leaf number in the 17/17 regime compared with 10/24, but had the same shoot fresh weight in both regimes. Whilst Chinese cabbage, endive and escarole were all taller as a result of plant stretch in the 10/24 treatment, celery was in fact taller in the 17/17 treatment compared with 10/24. This plant stretch in response to high day temperature (sometimes referred to as positive DIF) has been reported in other species e.g. some bedding plants, although species sensitivity varies which may explain the results for celery. Celery is also different to the other species with more petiole extension but since high day temperature has been shown to increase internode length it seems unlikely that the explanation for this lack of difference at assessment stage was due to differences in plant habit.

Hence whilst these species are capable of producing equivalent shoot weight in both a fixed and variable temperature regime so long as they experience comparable average temperature, the high day temperature approach may produce unacceptable transplant quality, because of elongated stems, resulting in 'leggy' plants. In practise one would not expect the extremes in temperature achieved in these experiments where the aim was to examine the worst case scenario of the temperature regimes tested. Temperature integration (Ti) would normally use high temperature vent set points allowing temperature to rise higher than normal prior to venting when solar gain is available. This builds up temperature credits i.e. where the excess temperature achieved above target level can be traded off when heating would normally be called for so long as a suitable rolling average temperature is achieved. The experimental 10/24 regime however had a small (1°C) differential between heat and vent set points to keep night temperature down to the 10°C set point. In practise a grower would have a higher vent set point and therefore achieve a higher night temperature requiring less heat during the day to achieve the desired 24 hour average temperature which in turn would create less plant stretch. Whilst energy savings have been demonstrated through the use of Ti, previous work (Adams, 2006) has indicated how low day temperature combined with higher night temperature has potential to generate extra energy savings. Allowing day temperature to fall whilst making up to the desired average through heating at night, would also be expected to produce more compact plant habit rather than the stretched habit seen with higher day temperature. These types of settings will be evaluated in 2009.

The impact of propagation treatments at harvest varied between batches, and therefore time of planting, and also between species. For celery and Chinese cabbage, there were significant levels of bolting recorded only in the earliest batches planted. Hence suitable plants were produced with lower average propagation temperature than is currently used commercially for batches of plants transplanted beyond week 13, a similar result was also found in 2007 for Chinese cabbage. Celery was transplanted later in 2007 but also had no bolting for transplanting beyond week 17 when propagated at 14°C. There is some indication from the celery data, that lower propagation temperature may result in lower head weight, which could be compensated by a longer growing period; Chinese cabbage head weight however was not influenced by propagation temperature. For the earliest plantings of the season however, an average propagation temperature of around 17.5°C reduced the amount of bolting at harvest compared with an average propagation temperature of around 14°C. It was also possible to allow temperature to vary (10/24) without increasing the amount of bolting at harvest providing a suitable average temperature was achieved (around 17.5°C). In fact the 10/24 treatment gave a slight reduction in bolting compared with the 17/17 treatment in some cases.

Where celery and Chinese cabbage transplant size was varied and samples taken on a fixed date, smaller transplants had less bolting than larger transplants when planted in weeks 10-13. Whilst the design of the trial made it necessary to harvest on a fixed date, in practise growers would harvest plants when a suitable weight has been achieved and as early as possible so long as the product may be sold. Hence larger transplants may be expected to be harvested sooner than smaller ones assuming the differences at transplanting stage remain. Head weight data assessed at marketing may be expected to indicate if transplant size treatments had an impact on potential differences in harvesting date and in fact there were no significant differences between transplant size treatments for either celery or Chinese cabbage in these early batches of plants that had some differences in bolting. This may suggest that small transplants planted early in the season were no worse than larger ones in terms of risk of bolting. However, later in the season, larger celery transplants had greater head weight at harvest than the smaller transplants suggesting that larger transplants may be harvested sooner and therefore with potentially less bolting. The lack of difference in head weight in earlier batches may have been due to the presence of the bolted stem itself which would be expected to increase fresh weight.

In contrast, where size of transplant was varied by sowing seeds on the same date and moving them from propagation according to size achieved, larger transplants had less bolting than smaller ones. In this approach however, the smaller transplants are also transferred out of the heat of propagation into the lower weaning/field temperatures sooner and hence may be expected to progress towards flowering sooner. It is clear therefore that methods of imposing differences in transplant size as well as methods of assessing the impact of such treatments will influence the result achieved. This issue will be examined in 2009 using plots at Wellesbourne where sequential samples may be taken in order to determine a suitable harvest date for each treatment based on representative plants of that treatment reaching a suitable size (weight).

Endive and escarole were more susceptible to bolting than Chinese cabbage and celery but responded similarly to the differences in transplant size i.e. more bolting in larger transplants than smaller ones with differences between treatments occurring through to the latest plantings in weeks 15-17. Where conditions had promoted high (89% +) levels of bolting in endive, transplant size made no difference to the levels of bolting at harvest stage. Interpretation of this data follows the same arguments discussed for Chinese cabbage and celery above. There does appear to be potential to use smaller transplants even of these more sensitive species providing adequate head weight can be achieved which will be assessed in 2009.

As with transplant size, propagation temperature was irrelevant for batches of endive and escarole with the highest levels of bolting. However where levels of bolting were lower, there was more bolting from the lowest propagation temperature than the two higher temperature treatments. As with celery and Chinese cabbage, having a night temperature at 10°C with compensation during the day to achieve a suitable average temperature was no worse, in terms of risk of bolting, than the more stable 17/17 regime. In fact lower bolting was associated with the 10/24 treatment than the 17/17 for some batches of plants. Propagation temperature continued to have a significant effect on endive and escarole through to the end of the experiment (week 15-17) and hence whilst maintaining an average temperature as high as 17.5°C beyond the earliest plantings of celery and Chinese cabbage is less critical, it is important to hold a higher average temperature for endive and escarole at least within the period investigated here. Propagation temperature had less influence over the weight of endive and escarole heads than over levels bolting, but where differences were found, lower propagation temperature resulted in lower head weight, with no differences between the fixed or variable approaches to the higher propagation temperature.

Conclusions

Bolting of all species responded to average propagation temperature indicating potential for energy saving propagation regimes where temperature is allowed to fluctuate providing a suitable average is maintained.

High day temperature had a negative impact on transplant quality of Chinese cabbage, endive and escarole and hence energy saving regimes that favour lower day and higher night temperature may be better suited to these species than the high day low night regime tested in 2008.

Allowing temperature to fall as low as 10°C combined with much higher (around 24°C) temperatures in other parts of the day may reduce bolting compared with a more stable 17°C heat set point throughout. However, the influence on plant quality needs to be considered as noted in the previous point.

Chinese cabbage, endive and escarole produced equivalent transplant and final head weight from both the fixed (17/17) and the variable (10/24) propagation regimes that produced comparable average temperature.

Celery transplant and final head weight responded to propagation temperature differently to the other species with the fixed 17/17 regime favouring highest weight. However given the lack of response beyond the very earliest plantings it may be still be suitable for propagation in variable temperature regimes where there are several species within the same growing zone.

The consequence of varying transplant size varied according to how treatments are imposed and assessed. A longer production period in the field may be necessary for smaller transplants compared with larger ones but the risks of reducing the size of transplants in terms of bolting may be less severe than originally anticipated. Further work is planned in 2009 to resolve interpretation of this data.

Technology transfer

HDC News article: Secrets of bolting unlocked, p18-20 issue148, November 2008.
Review meeting with steering group (including 5 industry representatives) on 10/10/08.

Glossary

Bolting: Bolting is the growth of an elongated stalk with flowers grown from plant's apex. This condition occurs in plants that are grown for their leaves.

Chitted: When the seed coat has split and the seedling is just beginning to emerge.
Floral initiation: When the apex has been triggered to produce flowers.

Juvenile: When plants are incapable of responding to signals that would normally promote flowering.

Leaf initiation: When the apex has been triggered to produce leaves.

Vernalized: In the context of this report it plants are considered to have vernalized when they have received sufficient low temperature for floral initiation.

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Appendix. Photographs of treatments at transplanting stage.

Week 10 (cs) Endive (planted 11/3/08)

Week 11 Endive (planted 11/3/08)

Week 13 Endive (planted 27/3/08)

Week 14 (cs) Endive (planted 8/4/08)

Week 15 Endive (planted 8/4/08)

Week 17 Endive (planted 22/4/08)

Week 10 (cs) Escarole (planted 11/3/08)

Week 11 Escarole (planted 11/3/08)

Week 13 Escarole (planted 27/3/08)

Week 14 (cs) Escarole (planted 8/4/08)

Week 15 Escarole (planted 8/4/08)

Week 17 Escarole (planted 22/4/08)

Week 10(cs) Celery (planted 14/3/08)

Week 11 Celery (planted14/3/08)

Week 13 Celery (planted 27/3/08)

Week 14(cs) Celery (planted 10/4/08)

Week 15 Celery (planted 10/4/08)

Week 17 Celery (planted 23/4/08)

Week 10 (cs) Chinese cabbage (planted 13/3/08)

Week 11 Chinese cabbage (planted 13/3/08)

Week 13 Chinese cabbage (planted 26/3/08)

Week 14 (cs) Chinese cabbage (planted 9/4/08)

Week 15 Chinese cabbage (planted 9/4/08)

Week 17 Chinese cabbage (planted 23/4/08)