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Headline

If space is a limiting factor during the production season, cold storage of bedding plant plugs can be used in the short term (up to 7 days) to maintain quality in plugs destined directly for sale, or longer (up to 21 days) in the case of plugs being held prior to transplanting into the final unit. However, to achieve successful storage care must be taken in the choice of plant species placed into store, the storage temperature, the duration of storage and any disease prevention measures undertaken during storage.

Background and expected deliverables

Accurate plant scheduling has become a critical requirement of successful bedding plant production in recent years. Customers increasingly demand more numerous batches of plants of varying species and varieties, delivered on a range of dates in order to satisfy fluid market demands. This applies as much to plant propagators supplying young plants as it does to growers supplying finished plants.

Through the spring months, the situation is compounded by the effects of the prevailing weather conditions, which not only affect rates of plant growth but also dictate the intensity and duration of demand for bedding plants. Scheduling techniques are critical through this period to maximise sales and minimise wastage.

Various techniques to delay plug plant development and growth are used in the bedding plant industry including: sub-optimal growing temperatures, reduced watering regimes, nutrient restriction (specifically phosphorus), physical means (such as pinching and cutting back) and the use of plant growth regulators. All these techniques however rely on the availability of suitable production space, if space is limited, holding back plugs can be difficult without loss of quality.

Cold storage allows bedding plant plugs to be held without tying up valuable production space. Cold storage of bedding plant plugs is not a novel alternative method, it is currently used by bedding plant growers in the USA and in part by a small number of bedding plant propagators in the UK. However, the procedure is not fully understood by growers and its potential applicability, including the financial benefits of cold storage are not yet appreciated by the industry as a whole. This project was designed to be part technology transfer (existing available information was collated in PC 196 Interim Report 2003 – Literature Review) and part experimental, generating further detailed data specific to the UK bedding plant industry.

The expected deliverables from this study include:

- Determination of the responses to cold storage of a range of bedding plant species.
- Information on the effects of cold storage over a four week period on plug and final plant quality.
- Identification of practical and cost effective storage regimes for bedding plants.

The experimental data should allow individual growers and propagators to develop storage regimes appropriate to their own specific circumstances thus enabling them to meet marketing targets and reduce production losses. The information generated should also provide guidance on suitable storage regimes during the transportation of bedding plant plugs.

Summary of the project and main conclusions

The trial was designed to evaluate the commercial viability of cold storing bedding plant plugs over a short time period. Twelve different bedding plant species were held in cold stores in the dark at either 4°C or 8°C for a four week period. The plugs were raised on a commercial propagation nursery in 405 or 264 plug trays and placed into experimental cold stores (direct expansion type stores) on the 6 May 2003. The control plugs were placed on a bench in a glasshouse and either left untreated or treated weekly with a spray of paclobutrazol (Bonzi) applied at 1.25 ml/litre of water. The two control treatments represented 'optimum storage conditions' to allow a direct comparison with the cold stored plug material. 72 plugs from each plant species in each storage regime were then transplanted each week over the four week period into double six polystyrene packs using a commercial growing media. Plug quality, mortality rates and disease levels were recorded whilst the plugs were in store. Post transplanting, plant quality, mortality rates and the time to first and full flower were recorded.

Treatment summary – plant species, plug size and storage regime

Species	Plug tray size		Individual treatments applied to the plugs of each species prior to transplanting
	405	264	• Storage on bench in glasshouse for 0-4 weeks (control). • Storage on bench in glasshouse for 0-4 weeks with weekly Bonzi application (control). • One week in cold storage at 4 or 8°C. • Two weeks in cold storage at 4 or 8°C. • Three weeks in cold storage at 4 or 8°C. • Four weeks in cold storage at 4 or 8°C.
Alyssum	3		
Antirrhinum	3		
Begonia	3		
Dahlia	3		
Geranium		3	
Impatiens	3		
Lobelia	3		
Marigold	3		
Nemesia	3		
Petunia	3		
Salvia		3	
Verbena	3		

Plug quality during storage

The quality of the plugs in store was scored to three grades. A 'marketable' score was given to plug material which would be commercially acceptable if received from a propagator, a second score of 'acceptable' was given to plug material which was of a lower standard, but was still good enough to be transplanted to produce a finished crop. The main difference between the two levels was usually the degree of leaf paleness or internode stretching. A third score of 'unacceptable' was given to material which was either poor in the plug tray or of a quality which could still be transplanted but would probably give rise to sub-standard finished plants.

As expected, the plug plants stored under glasshouse conditions generally held well, with most species remaining compact and acceptable for two weeks or more. There was little difference in the observed overall quality between the plugs treated with paclobutrazol (Bonzi) and those that received no treatment. The only difference was a slight reduction in the degree of stretching noted on some plant species in response to the growth regulator treatments. No incidence of disease was noted on the plug plants stored under glasshouse conditions. This highlights the fact that plug plants can be stored adequately under glasshouse conditions for a period of weeks if they are properly cared for. Placing plug trays out onto floors or benching (as opposed to leaving them on Danish trolleys) and providing the plug plants with sufficient water and nutrition can dramatically extend the shelf life of the plant material.

Plug plants held at 4^{o}C appeared to store reasonably well with many species still commercially marketable after one and occasionally two weeks and still acceptable after three or even four weeks. The plugs stored at 8^{o}C did not maintain quality for quite the same length of time, with deterioration noticeable on several species after two weeks of storage. At this temperature, plant growth continued, albeit slowly. However, without light, plants etiolated becoming pale and stretched.

Chilling injury on plugs in cold storage was noted on several plant species including impatiens, nemesia, dahlia, salvia, verbena and marigold. The degree of damage varied from entire plant death to leaf tip or growing point necrosis. Symptoms were most severe on impatiens, nemesia and dahlia and less so on salvia, verbena and marigold. The symptoms on many species appeared from the second to third week of storage onwards and were visible on material stored at both temperatures.

Recommended maximum cold temperature storage periods for a range of bedding plant plugs

	4°C storage		8°C storage	
Species	*Commercial plug quality**	*Acceptable quality plug•*	*Commercial plug quality**	*Acceptable quality plug•*
Alyssum	7 days	14 days	7 days	7-14 days
Antirrhinum	14 days	21-28 days	7-14 days	21-28 days
Begonia	14 days	21-28 days	7-14 days	21-28 days
Dahlia	7 days	21 days	7 days	14-21 days
Geranium	7-14 days	28 days	7 days	21 days
Impatiens	0-7 days	0-7 days	0-7 days	0-7 days
Lobelia	14 days	28 days	7-14 days	21-28 days
Marigold	14 days	21-28 days	14 days	21-28 days
Nemesia	7 days	14 days	7 days	14 days
Petunia	7-14 days	21 days	7 days	21-28 days
Salvia	7 days	21 days	7 days	14-21 days
Verbena	7-14 days	21 days	7 days	14-21 days

* plugs for direct sale

• plugs held prior to transplanting

Within two weeks of storage, the first signs of disease were noted on some of the plant species stored at 8^{o}C. *Sclerotinia* was noted on the alyssum and marigold and *Botrytis* was noted on the impatiens, petunia, geranium and marigold, primarily on damaged leaf tissue or lower leaf

tissue. Only a low level of *Botrytis* was noted on the geraniums stored at 4°C, the lower temperatures restricting the speed of any disease development and colonisation. An application of iprodione (Rovral WP) made to all the plug plants in cold store at the beginning of the third week of storage had a limited effect on disease levels, highlighting the need for careful monitoring and control of the storage environment, especially humidity levels.

Plant survival post transplanting

The lowest percentage of plant death was achieved uniformly for all species by holding the plugs in the glasshouse without any treatment (control). In general terms, with the exception of impatiens, dahlia and salvia, the 4°C storage regime gave rise to less plant mortality following transplanting than the 8°C storage regime. In terms of individual plant species, the two cold storage regimes had a variable effect on plant mortality following transplanting. Mortality rates varied from 1-4% in the case of begonia, marigold and petunia, up to over 80% in the case of impatiens and nemesia. Both of these species exhibited chilling injury in store. Any plugs showing chilling injury were not transplanted, however plug damage was not generally expressed until the second week onwards (especially at 4°C) and then only in patches rather than across the tray as a whole. The results show that even if damage is not expressed by the plugs during storage, chilling injury can still have a dramatic effect post transplanting, whether shading is used or not to aid plant establishment.

The length of time the plugs were held in storage affected the mortality percentage for some species. Two weeks at 4°C had little effect on the survival of the majority of species being investigated. However longer term storage, or storage at 8°C, did increase losses post transplanting for several plant species.

High mortality in stored plugs is a serious loss to the propagator. However, this loss is compounded when seemingly healthy plug plants, which have been chilled or stressed, are transplanted by a grower into retail packs and then subsequently die. The process of replacement due to plant death or poor quality is a costly exercise (extra plant and labour costs and the potential costs of lost business) and leads to a reduction in profitability. This trial highlights the fact that chilled / stressed plugs don't always immediately show any symptoms of damage especially within the first or second week of storage.

Plant quality post transplanting

For the majority of plant species, plugs transplanted into packs developed into plants which were at least of acceptable quality if not higher, irrespective of storage method. The key exceptions to this were cold stored impatiens and nemesia. After one week of storage at 8°C or two weeks storage at 4°C, impatiens plug quality had declined so much that the plants never recovered after transplanting. Plants either died or remained of poor quality throughout the trial. In the case of nemesia, a similar situation occurred with plug plants stored at 8°C for three weeks or more.

Longer periods of storage, usually in excess of two to three weeks also reduced plug quality, which had an effect on the final plant quality, although in most cases the final plant quality was still acceptable. This deterioration was mainly noted with cold stored plugs, for example impatiens, nemesia, dahlia, salvia and marigold stored at both 4°C and 8°C and alyssum, petunia and verbena stored at 8°C.

Time to first flower and full flower post transplanting

Time to first and full flower was species dependent, however most of the plant species attained full flower within five weeks of transplanting. An effect of cold storing the plugs in the dark on time to first and full flower was noted for all plant species in the trial.

In the case of plugs stored in the glasshouse on benches, the number of weeks the plants took to both come into flower and attain full flower generally declined in relation to the number of weeks the plugs were held. This was because the plugs and plants were exposed to natural day length, light levels and glasshouse temperatures and therefore flower initiation could occur at the natural time in response to day length. As the season progressed and temperatures and day lengths increased, plant development rates also increased reducing the time taken to flower.

The cold storage regimes appear to have halted flower initiation and / or development for all plant species. It may be that storing the plugs in the dark prevented flower initiation from occurring or that the low temperatures prevented further flower development (initiation having occurred prior to storage). Whatever the reason, flower development did not progress until the plugs were taken out of cold store. Once out of store and transplanted, flower development occurred over a time span comparable to those plugs that had been transplanted at the beginning of the trial.

Conclusions

The results from the trial highlight the importance of careful plug management even if the plugs are only held in a glasshouse. Placing plug trays on the floor or bench of a glasshouse, as opposed to leaving them on a Danish trolley, and carefully watering and feeding them can substantially extend the shelf life of the plugs.

The study indicated two ways in which low temperature storage might be used if production space is limited. Firstly, storage of plugs destined for direct sale. The trial highlighted the fact that to maintain the necessary quality, plugs raised for commercial sale should be stored for the minimum period only in cold store. In the case of most of the plant species examined in the trial this period should not exceed 7 days at $4^{o}C$. In the case of a small number of plant species (for example begonia, lobelia and antirrhinum) this period could be extended to possibly 14 days. In the case of impatiens plugs, very short term storage should only be considered or possibly storage at a higher temperature attempted.

Secondly, the technique may be used to store plugs prior to transplanting to produce finished plants. In this scenario, out of store plug quality does not have to be as high, as it is finished plants rather than plugs, which are being sold. In this case the trial demonstrated that plugs could be held for longer periods of time (up to three or possibly four weeks) if a short term drop in quality could be accommodated. This loss of quality usually equated to a loss of leaf colour intensity, lower leaf yellowing and slight internode extension. The trial indicated that plugs of a lower quality still produced quality finished plants if managed carefully.

The suitability of plug storage conditions should also be extended to the storage regimes used to transport plugs. Appropriate temperatures and environmental conditions should be used during transit to maintain plug quality without causing chilling injury.

Financial benefits

The precise financial benefits of using cold stores to hold bedding plant plugs are generally determined by individual nursery circumstances. The availability of suitable facilities and labour will determine the most appropriate method for holding bedding plant plugs on any particular nursery. If space is not an issue plugs can be held in glasshouse without any substantial loss of quality. However if space is limiting, the results of this trial have shown that certain bedding plant species can be stored at low temperatures for up to three to four weeks.

Cost benefit analyses were undertaken as part of the literature review accompanying PC 196 and they highlighted a positive benefit from using cold stores in the following areas;

- *Scheduling crops and reducing wastage* – depending upon the size of the store and the number of plug trays stored, cold stores can actually show a benefit if they reduce plug wastage by as little as 2.5%.

- *Holding crops prior to transplanting* – when hold ups occur during production it can be more cost effective to hold plugs in certain stores for a short while (1-2 days) prior to transplanting than it is to unload and then reload them onto Danish trolleys.

- *Substitution for glasshouse space* – cold stores can be cost effectively used as a substitute for glasshouse space, depending upon the plug tray stack height on the trolley in the cold store.

- *Use of the cold store for seed germination and dormant plant storage* – increases in the germination level of primrose by only 7% was shown to recoup the cost of using a cold store for this purpose in seed cost alone.

Other issues noted as a result of this trial include;

The frequency of watering the plugs in cold store depends upon the type of cold store used. Refurbished refrigerated lorry bodies are generally the cheapest units to purchase or lease and will therefore be used most frequently. However, the direct expansion cooling units found in such bodies tend to have high rate of air circulation that can quickly dry plugs out (especially very small plugs for example 405's), necessitating frequent inspection and irrigation. The extra cost of this labour to remove and water plugs held on Danish trolleys on a weekly basis should be taken into consideration when undertaking any costings exercise.

Although plugs stored in purpose built stores may not require the same frequency of irrigation, they should still be carefully monitored as there appears to be a higher risk of disease due to the higher humidity levels maintained within these stores.

Action points for growers

If glasshouse space is a limiting factor at certain times of the year and plug plants need to be held for some reason then cold storage facilities should be considered. Various types of potential cold stores and their associated costs were discussed in the literature review (PC 196 Interim Report). The trial highlighted several factors that need addressing in order to minimise plug plant losses in store.

- **Cold storage facilities**

The choice of cold store type will affect the plug management required. Air circulation within the store is a critical factor, good air movement reduces the risk of high humidities building and diseases becoming established on plant material. Conversely however, too much air movement can lead to the rapid desiccation of plugs necessitating a frequent irrigation programme.

- **Storage temperatures**

As an average storage temperature, 4^{o}C appeared to be more appropriate than 8^{o}C. The warmer regime allowed the continued development of many of the plant species in cold store resulting in pale, stretched plugs after several weeks of storage. The warmer storage regime also permitted the more rapid development of diseases such as *Botrytis* on damaged or senescing plant tissue.

- **Store management**

Frequent checks on plugs in store are needed to monitor quality levels and assess potential disease problems. Appropriate fungicide spray programmes need to be in place if necessary, one-off treatments are limited in their effect. Good store hygiene is essential to minimise disease carry over between crops in store. American research (Heins *et al*., 1992 and 1995) has indicated that a low level of light (in the range of 1μmol m^{-2} s^{-1}) may help to prevent etiolated plant growth, especially if storage temperatures are sub-optimal and there is a risk of plant growth in store.

- **Plants species stored**

Plant species which are susceptible to chilling injury, such as impatiens, should ideally not be cold stored at the temperatures examined. Many plant species are tolerant of cold storage, but the storage period should still be kept to a minimum in order to reduce any potential loss of quality or plant death post transplanting.

- **Plant care prior to storage and post storage**

Any plug material must be of high quality prior to storage. Plugs should be watered before storage, but foliage must be dry before the plugs are placed into store. Shading cold stored plugs post transplanting (especially on bright days) reduces stress and aids more rapid plant establishment.

Science section

Introduction

Accurate plant scheduling has become a critical requirement of successful bedding plant production. Increasingly the demand is for more numerous batches of plants of varying species and varieties, delivered on a range of dates in order to satisfy fluid market demands. This applies as much to plant propagators supplying seedlings and plug plants as it does to growers supplying finished plants.

Various techniques to delay plant development and manipulate growth are currently used in the bedding plant industry including: sub-optimal growing temperatures, reduced watering regimes, nutrient restriction, physical means and the use of chemical plant growth regulators. All these techniques however rely on the availability of production space. If space is limited holding back plugs without loss of quality can be difficult. Cold storage allows bedding plant plugs to be held without the need for production space.

Cold storage of bedding plant plugs is not a new concept, research examining the potential to store plugs at low temperatures was undertaken in the USA and published by Heins *et al* in 1992 and 1995 and by Kaczperski and Armitage in 1992. Much of the information published since 1995 however has simply been based on this earlier pioneering work.

In the most extensive piece of work, Heins and his colleagues examined the potential to store 19 different bedding plant species at storage temperatures ranging from 0-12.5°C and over time periods varying from one to six weeks. Optimum temperatures and maximum storage periods were derived (Table 1) from data collected on days to flower under glasshouse conditions and percentage mortality of plugs following the storage period.

Whilst this information has useful merit as a guide to low temperature storage, it was carried out under growing conditions specific to the USA. Therefore, the present study was designed to repeat this work, with plugs produced in the UK industry and grown on using facilities likely to be used by UK growers. The post transplanting assessments were also expanded to not only include plant survival and flowering times but also the commercial quality of the final plant produced.

The main objectives of the study were threefold;

- Investigate low temperature responses in a range of bedding plant species
- Examine the effects of storage on plug and final plant quality
- Identify practical and cost effective storage regimes for bedding plants.

The issue of light provision during storage was considered during the design of the trial, but was rejected in favour of a simpler dark storage option, allowing the number of bedding plant species examined in the trial to be maximised.

The trial was designed from the outset to be a demonstration trial, as there was no plot replication, statistical analysis of the results was not appropriate. However it was envisaged that the experimental data generated by the trial would allow individual propagators and growers to develop storage regimes appropriate to their own specific circumstances, both for the storage and transportation of plugs.

Table 1. Optimal plug storage temperature and maximum durations. (Adapted from Heins *et al*., 1995; Styer and Koranski, 1997)

Species	Optimal storage temperature °C	Maximum storage in dark (wks)	Maximum storage in light (wks)*
Ageratum	7.5	6	6
Alyssum	2.5	5	6
Begonia (fibrous)	5.0	6	6
Begonia (tuberous)	5.0	3	6
Celosia	10.0	2	3
Cyclamen	2.5	6	6
Dahlia	5.0	2	5
Geranium	2.5	4	4
Impatiens	7.5	6	6
Lobelia	5.0	6	6
Marigold (French)	5.0	3	6
NG Impatiens	12.5	2	3
Pansy	2.5	6	6
Petunia	2.5	6	6
Portulaca	7.5	5	5
Salvia	5.0	6	6
Verbena	7.5	1	1
Vinca	10.0	5	6

- Minimum of 1μmol m^{-2} s^{-1} irradiance

Material and Methods

The bedding plant species used in the trial are listed below. The age of the plugs, as weeks from sowing on the day of receipt at Writtle College, are indicated in brackets.

Alyssum '*Wonderland Mixed*'	(3)	Lobelia '*Fountain Mixed*'	(3)
Antirrhinum '*Floral Showers Scarlet*'	(4)	Marigold '*Bonanza Mixed*'	(3)
Begonia '*Senator Mixed*'	(6)	Nemesia '*Nebula Mixed*'	(5)
Dahlia '*Figaro Mixed*'	(3)	Petunia '*Mirage Mixed*'	(4)
Geranium '*Maverick Appleblossom*'	(5)	Salvia '*Vanguard*'	(4)
Impatiens '*Deco Red*'	(4)	Verbena '*Obsession Mixed*'	(5)

The plug plants were received from Roundstone Nurseries on 1 May 2003 and placed on the floor of a single span glasshouse under 30% green shade netting to minimise potential plant stress. The plugs were supplied in 405 trays, except for geranium and salvia, which were supplied in 264 trays.

All the plug plants were quality inspected upon delivery to the trial site, at Writtle College, by Wayne Brough, ADAS Horticultural Consultant, and Robyn Taylor, Writtle Trials Officer. It was confirmed that all of the material was of a uniform, commercial quality except for the trays of petunia and anthirrhinum, the plants being a little too small. The plugs were watered as required and liquid fed on 3 May with a Sangral 3:1:3 fertiliser, applied at a dilution rate of 1:400. The plugs were held in a glasshouse until the 6 May to allow for a little extra growth on the petunia and antirrhinum plugs before the trial commenced.

All the plug trays were watered on the morning of the 6 May and left for 1-2 hours to ensure the foliage was dry. The plug plants were then either placed directly onto a bench in the single span glasshouse (control) or onto Danish trolleys and moved into cold stores (direct expansion cold stores - 3 kW; FX 56; room size approximately 8 m^3 – Figure 1) maintained at 4 or 8°C (treatments). The stores were operated without light and individual plug trays were watered as necessary, typically every seven to ten days. The air flow through the stores was such that plug desiccation was not a real issue. All the plugs were inspected for disease and quality at weekly intervals, and any comments recorded (Table 3 and Appendix 1). Any fungicide applications over the plug plants were carried out as necessary to keep disease development in check. Data loggers were used to record the cold store and glasshouse temperatures during the four week storage period (Figure 2).

Half of the control plugs which were placed on the bench in the glasshouse were left untreated, whilst the other half were treated with the plant growth regulator paclobutrazol (Bonzi) applied as a fine mist at 1.25 ml per litre of water at weekly intervals. All the control plugs were watered as necessary and fed with Sangral 3:1:3 fertiliser (1:200 dilution) once a week throughout the four week storage period.

Each week over the four week storage period 72 plants from each treatment were transplanted by hand into polystyrene double six packs containing SHL Potting and Bedding Compost (pre-watered prior to transplanting).

Figure 1. Writtle College experimental cold store

Plug plants for transplanting were taken as continuous rows from the appropriate plug trays. Both sets of 'control' plugs (with and without Bonzi) were transplanted at T0 (first day of cold storage) and then subsequently at T1, 2, 3 and 4 (weekly intervals). Plugs from cold storage were transplanted at T1, 2, 3 and 4 (weekly intervals; Table 2).

Table 2. Treatment week showing the date the plugs were transplanted out of storage

T0	No storage	Control plugs only	6 May 2003
T1	1 week storage	All storage treatments and control plugs	13 May 2003
T2	2 weeks storage	All storage treatments and control plugs	20 May 2003
T3	3 week storage	All storage treatments and control plugs	27 May 2003
T4	4 weeks storage	All storage treatments and control plugs	3 June 2003

Colour photographs were taken at regular intervals throughout storage, a selection are shown in Appendix 4.

Plants from cold store were held under 30% green shade netting for three to five days (determined by the prevailing weather conditions) after transplanting to aid establishment. Established double six packs of impatiens and begonias were also shaded with 30% netting as required on particularly bright days.

The glasshouse used in the trial (to hold the control plugs and grow on the plants after transplanting) was a single span unit with automatic venting and pipe heating. The plants were placed on Mypex laid over prepared beds. The beds were prepared by placing upturned polystyrene packs over the soil to ensure drainage and to raise the bed level with the paths. The packs were then covered with capillary matting and Mypex. Plants were hand-watered using a lance and fed with Sangral 3:1:6 (diluted at 1:200) after two weeks, and then at least weekly to the point of marketing.

Data recorded during the trial included: quality of the stored plugs, plug mortality, disease incidence on the plugs, plant survival post transplanting, plant quality, days to first flower and days to full flower. The plant quality score was based on a qualitative scoring system where '4' represented the highest quality plant and '0' a plant of the poorest quality. The scoring system assessed leaf colour, plant habit and height as separate assessment criteria. Each plant species was assessed independently as to the general appearance and growth habit. However, a generalised appearance score was used as a guide and is shown in Appendix 2 (along with photographs).

Assessments of time to first flower and full flower were undertaken weekly. The week in which colour was seen in the first flower bud of any of the 72 plants in the sample population, was taken as the time to first flower. Similarly, the week in which all the plants in the sample were in flower was taken as the time to full flower.

The majority of the records were taken over five weeks after transplanting, although in the case of dahlia and geranium the time to full flower was not achieved until after nine or ten weeks.

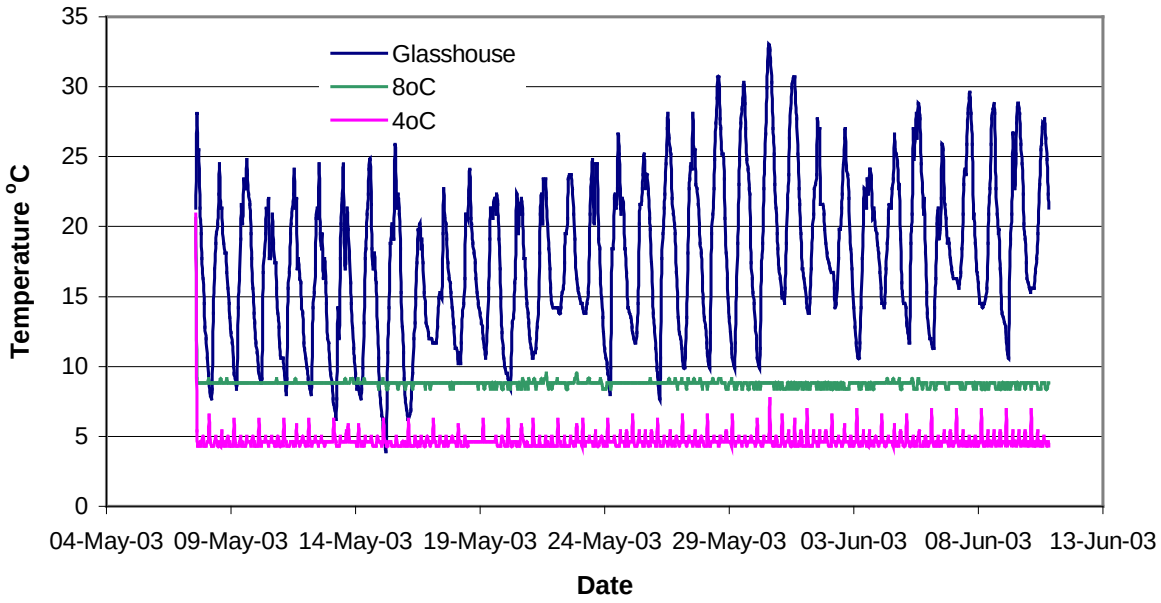
Results and Discussion

Cold store performance

The two cold stores used in this study were set at nominal, constant temperatures of 4 and 8°C. Figure 2 shows the temperatures recorded by the data loggers over the one month storage period of the trial. The graphs show the typical temperature cycling pattern of most commercial cold stores. The temperature achieved is, typically, within plus or minus 1°C of the set point in an effective facility. The store set at 4°C cycled from 4 to 5°C (occasionally to 6°C or more). These fluctuations represent periods when the door was open. The 8°C store cycled between 7.5 and 8.5°C and because of the higher storage temperature showed slightly less disturbance when the door was opened.

The variation in temperature experienced by the plug plants held in the glasshouse is also indicated on the graph, showing night-time minima as low as 5°C and daytime maxima as high as 32°C as recorded by a shaded data logger. No heat was applied through the period of the trial and venting was set to occur at 12-15°C.

Figure 2. Temperature in glasshouse and cold stores



Plug quality during storage

The overall quality of the plugs was assessed each week over the four week storage period by Wayne Brough, ADAS Horticultural Consultant (Table 3). Where possible, the quality of the plug trays was scored to three grades. A 'marketable' score was given to plug material which would be commercially acceptable if received from a propagator, a second score of

'acceptable' was given to plug material which was of a lower standard, but was still good enough to be transplanted to produce a finished crop. The main difference between the two levels was usually the degree of leaf paleness or internode stretching. A third score of 'unacceptable' was given to plant material that was either poor in the plug tray or of a quality that could still be transplanted but would probably give rise to sub-standard finished plants. The incidence and level of disease occurring on the plugs in cold storage was also commented upon and these data are presented in Appendix 1.

The plug plants stored under glasshouse conditions generally held well, with most species remaining compact and acceptable for two weeks or more. However, several of the plant species began to stretch after two to three weeks in the plug tray including impatiens, antirrhinum, dahlia, verbena, marigold and salvia. After the first week of storage in the glasshouse the alyssum plugs began flowering, whilst flower bud was noted in the impatiens and marigold plugs after two to three weeks. There was little difference in observed overall quality between the plugs treated with paclobutrazol (Bonzi) and those that received no treatment. The only difference was a slight reduction in the degree of stretching noted on some plant species (lobelia, verbena, petunia and geranium) in response to the growth regulator treatments. No incidence of disease was noted on the plug plants stored under glasshouse conditions.

This observation highlights the fact that plug plants can be stored adequately under glasshouse conditions for a period of weeks if they are properly cared for. Placing trays out on floors or benching (as opposed to leaving them on trolleys) and providing the plug plants with sufficient water and nutrition can dramatically extend the shelf life of the plant material.

Plug plants stored at 4^{o}C appeared to store reasonably well with many species still commercially marketable after one and occasionally two weeks and still acceptable after three or even four weeks. The plugs stored at 8^{o}C did not maintain quality for quite the same length of time, with deterioration noticeable on several species after two weeks of storage. At this temperature plant growth continued, albeit slowly. However, without light, plants etiolated becoming pale and stretched.

Chilling injury on plugs in cold store was noted to some degree on several plant species including impatiens, nemesia, dahlia, salvia, verbena and marigold (Figure 3). The degree of damage varied from entire plant death to leaf tip or growing point necrosis. Symptoms were most severe on impatiens, nemesia and dahlia and less so on salvia, verbena and marigold. The symptoms on many species only appeared from the second to third week onwards and were visible on material stored at both temperatures. By the end of the four week cold storage period, most of the impatiens plugs were dead. Extensive die back was noted with the dahlia and nemesia plugs, chilling injury symptoms were obvious on the salvia and verbena plugs and leaf tip necrosis / odd plug death was noted on the marigold plugs. The symptoms were noted on plugs stored at both temperatures.

Within two weeks of storage, the first signs of disease were noted on some of the plant species stored at 8^{o}C. *Sclerotinia sclerotiorum* was noted on the alyssum and marigold and *Botrytis cinerea* (grey mould) was noted on the impatiens, petunia, geranium and marigold, primarily on damaged leaf tissue or lower leaf tissue. Only a low level of *Botrytis* was noted on the geraniums stored at 4^{o}C, the lower temperatures restricting the speed of any disease development and colonisation. As a result of this disease development, an application of iprodione (Rovral WP) was made to all the plug plants in cold store at the beginning of the

Table 3. Qualitative assessment of plugs during storage

Control - glasshouse storage no treatment (Week numbers refer to the period the plugs were held in plug trays on the bench)

Species	Comments
Alyssum	Plants remained reasonably compact throughout storage. Plugs began flowering within 1-2 weeks of receipt. Plugs marketable up to 1 week and then acceptable for another week. Plugs in full flower with pale foliage from week 3 onwards.
Antirrhinum	Plug plants quite small at delivery. Remained marketable into week 2. Plugs began to stretch and become pale, but still acceptable into weeks 3 and 4.
Begonia	Marketable for 1 week. Plugs pale and hungry, but remained compact, acceptable into weeks 3 and 4.
Dahlia	Marketable possibly into week 2. Some stretching afterwards, but foliage colour remained good. Acceptable into week 4.
Geranium	Marketable into week 2. Very slight stretching and reddening of foliage after 3 weeks. Acceptable into weeks 3 and 4.
Impatiens	Marketable for 1 week, acceptable up to week 3 when flower bud became visible and plugs began to 'mound' in growth.
Lobelia	Marketable for 2 weeks. Leaf colour remained good but plugs began to 'mound' into week 3. Acceptable to week 3, possibly week 4.
Marigold	Marketable for 1 week, acceptable from week 2 onwards. Flower bud developed during week 2-3, and plugs began to stretch.
Nemesia	Marketable for 1 week then acceptable for another 2 weeks. Plugs remained reasonably compact, but foliage bronzed.
Petunia	Marketable for 1 week, then acceptable through to weeks 3-4, although foliage began purpling in week 3.
Salvia	Marketable for 1 week, acceptable for another 2-3 weeks, although plugs became stretched and began to purple from week 3 onwards. third week of storage. However, this one-off fungicide treatment had a limited effect on disease levels, especially the levels of *Botrytis.* By the end of the four week storage period,
Verbena	Marketable for 1 week, acceptable for another 2-3 weeks, although plugs became stretched and began to purple from week 3 onwards.

Control - glasshouse storage with Bonzi treatment (Week numbers refer to the period the plugs were held in plug trays on the bench)

Species	Comments
Alyssum	Plants remained reasonably compact throughout storage. Plugs began flowering within 1-2 weeks of receipt. Plugs marketable up to 1 week and then acceptable for another week. Plugs in full flower with pale foliage from week 3 onwards.
Antirrhinum	Plug plants quite small at delivery. Remained marketable into week 2. Treatment limited the amount of stretching but plugs still became pale in colour, still acceptable into weeks 3 and 4.
Begonia	Marketable for 1 week. Plugs pale and hungry, but remained compact, acceptable into weeks 3 and 4.
Dahlia	Marketable possibly into week 2. Treatment reduced degree of stretching, and foliage colour remained good. Acceptable into week 4.
Geranium	Marketable into week 2. Reddening of foliage after 3 weeks. Acceptable into weeks 3 and 4.
Impatiens	Marketable for 1 week, acceptable up to week 3. Flower bud visible from week 3, but treatment limited stretching.
Lobelia	Marketable for 2 weeks. Leaf colour remained good. Acceptable to week 3, possibly week 4.
Marigold	Marketable for 1 week, acceptable from week 2 onwards. Flower bud developed during week 2-3.
Nemesia	Marketable for 1 week then acceptable for another 2 weeks. Plugs remained reasonably compact, but foliage bronzed.
Petunia	Marketable for 1 week, then acceptable through to weeks 3-4, although foliage began purpling in week 3.
Salvia	Marketable for 1 week, acceptable for another 2-3 weeks, plugs stretched slightly and began to purple from week 3 onwards.
Verbena	Marketable for 1 week, acceptable for another 2-3 weeks, although plugs began to purple from week 3 onwards.

4°C storage regime (Week numbers refer to the period of cold storage)

Species	Comments
Alyssum	Marketable for 1 week, most plugs acceptable into week 2, possibly week 3. Plugs began to stretch and become chlorotic from week 3. Symptoms not as severe as 8°C storage regime.
Antirrhinum	Marketable for 1-2 weeks (plugs small to begin with). Plugs acceptable to week 3-4, although they did become pale and stretched.
Begonia	Plugs stored well throughout the trial. Marketable to week 2, acceptable to week 4.
Dahlia	Marketable for 1 week and possibly acceptable into week 3, although plant death and leaf necrosis noted by week 3. Surviving plugs compact and still of good colour. Widespread plug loss by end of week 4.
Geranium	Marketable into weeks 1-2 and acceptable until week 4. Leaf yellowing, stretching and general paleness noted by week 4.
Impatiens	Marketable possibly to week 1 and possibly acceptable to week 2. Seedling damage and death from week 3 onwards.
Lobelia	Plugs stored well, marketable to week 2, acceptable to week 4. Plugs slightly pale by week 3.
Marigold	Marketable to week 1-2 and acceptable to week 4. Leaf tip damage noted from week 2 onwards. Plugs pale from week 3.
Nemesia	Marketable to week 1, acceptable to week 2-3. Plugs stretched and pale by week 3, plug death noted during week 4.
Petunia	Plugs stored moderately well, marketable to week 2, acceptable to weeks 3-4. Plugs pale by week 3, leaf yellowing and petiole etiolation noted by week 3-4.
Salvia	Marketable to week 1 and acceptable to week 3. Plugs pale by week 3 and plug death noted during week 4.
Verbena	Marketable to week 1, possibly 2 and acceptable to week 3. Leaf necrosis noted by week 3 and odd plug death by week 4. Plugs pale and stretched from week 3.

8°C storage regime (Week numbers refer to the period of cold storage)

Plant	Comments
Alyssum	Marketable for week 1, then signs of stretching and leaf yellowing from week 2. Plugs unacceptable from week 3-4.
Antirrhinum	Plugs marketable for 1-2 weeks and acceptable up to 3-4 weeks. Plugs became pale and etiolated.
Begonia	Plugs stored well throughout the trial. Marketable to week 2 and acceptable to week 4. Some leaf paleness noted.
Dahlia	Marketable into week 1 and possibly acceptable into week 3. Stretching noted in week 2. Plant losses and damage from week 3, symptoms possibly less than those under 4°C regime.
Geranium	Marketable into week 1, acceptable to week 2-3. Leaf yellowing evident from week 2, plants pale and stretched by week 3.
Impatiens	Marketable / acceptable to week 1. First signs of damage from week 2, widespread plug death from week 3.
Lobelia	Marketable to week 2, acceptable to week 3-4. Slight stretching and paleness to plugs by week 3.
Marigold	Marketable to week 1-2 and acceptable to week 3-4. Leaf tip damage from week 2, plant death during week 4. Plugs stretched and pale.
Nemesia	Marketable to week 1, acceptable to week 2. Leaf necrosis noted during week 2. Plugs stretched and pale by week 3, plug death noted by week 4.
Petunia	Marketable to week 1-2 and acceptable to week 3. Petiole elongation and loss of colour by week 3.
Salvia	Marketable to week 1 and acceptable to week 3-4. Plugs slightly more stretched and paler than 4°C regime material, but less damage noted, primarily leaf necrosis from week 3.
Verbena	Marketable to week 1 and acceptable to week 3. Leaf necrosis noted from week 3, but no plug death. Plugs paled and stretched noticeably from week 3.

Figure 3. *Botrytis* colonisation and chilling injury on plugs

Botrytis colonisation on lobelia

Botrytis colonisation on petunia

Chilling injury on impatiens

third week of storage. However, this one-off fungicide treatment had a limited effect on disease levels, especially the levels of *Botrytis.* By the end of the four week storage period, *Botrytis* was noted at some level on most of the plant species stored at 8°C and on the petunia, verbena and geranium stored at 4°C.

To minimise disease development on plugs in store the correct storage temperatures must be used in the first instance to reduce any potential plant damage or stress. Humidity levels immediately around the plugs need to be controlled via good air circulation within the store. If a fungicide treatment is still required, then a more intensive (possibly protectant) spray programme should be used, rather than a one-off treatment.

Plant survival post transplanting

The percentage mortality (plant death) of plugs transplanted into polystyrene packs after a storage period of up to 4 weeks is presented in Table 4. Ideally no losses (mortality of 0%) are desirable, as any plant death is an economic loss due to the cost of replacing the plant and the labour to do so. Practically, however losses of up to 5% may be more realistic due to damage and stress that may occur during the transplanting process. Therefore, any storage treatments that resulted in a mortality percentage of 5% or higher have been highlighted and must be considered with caution.

The lowest percentage of plant death was achieved uniformly for all species by holding the plugs in the glasshouse without any treatment (control). A similar result was achieved by holding plugs in the glasshouse with a weekly growth regulator treatment (Bonzi), except for the anomalous 12% loss, recorded for nemesia plants that had been held for three weeks. Plugs held in the glasshouse were placed on a bench (as opposed to being held on a trolley), and therefore received full natural daylight and minimal stress levels throughout the storage period. This along with regular inspections and the required cultural management resulted in a low mortality percentage post transplanting, even after several weeks of holding the plug plants.

In general terms, with the exception of impatiens and dahlia, the 4°C storage regime gave rise to less plant mortality following transplanting than the 8°C storage regime. In terms of individual plant species, the two cold storage regimes had a variable effect on plant mortality following transplanting. In the case of begonia, marigold and petunia, the two cold storage regimes gave rise to only very low levels of plant mortality. For most species, occasional losses slightly in excess of the 5% level were noted, for example alyssum, antirrhinum, geranium, lobelia, salvia and verbena. However, higher losses were experienced with impatiens, nemesia and to a lesser extent dahlia. All these three species exhibited chilling injury in store. Any plugs showing chilling injury were not transplanted, however plug damage was not generally expressed until the second week onwards (especially at 4°C) and then only in patches rather than across the tray as a whole. The results show that even if damage is not expressed by the plugs during storage, chilling injury can still have a dramatic effect post transplanting, whether shading is used or not to aid plant establishment.

The length of time plugs were held in storage affected the mortality percentage post transplanting for some species. Two weeks at 4°C had little effect on the survival of the majority of species being investigated. There was however substantial losses of impatiens, which suffered chilling injury with irreparable damage accumulating at low temperatures resulting in considerable levels of plant death, post transplanting, after the plugs had been in storage for over two weeks. Nemesia, dahlia, and salvia also showed susceptibility to storage at 4°C, however significant losses for these species only occurred after four weeks of storage.

Table 4. The percentage of plants dying after transplanting

Storage (weeks)	Treatment			
	No	Bonzi	4°C	8°C
Alyssum				
0	0	0		
1	0	0	0	0
2	0	0	0	4
3	0	0	0	3
4	0	0	0	12
Begonia				
0	0	0		
1	0	0	0	0
2	0	3	0	0
3	0	0	0	3
4	0	0	0	0
Geranium				
0	0	0		
1	0	0	0	3
2	0	0	3	6
3	0	0	2	0
4	0	0	0	2
Lobelia				
0	0	0		
1	0	0	0	0
2	0	0	0	0
3	0	0	7	0
4	0	0	0	7
Nemesia				
0	0	0		
1	0	0	0	1
2	1	0	0	15
3	4	12	4	37
4	0	3	6	83
Salvia				
0	0	0		
1	0	0	0	0
2	1	0	0	0
3	0	1	4	7
4	0	1	6	1

Storage (weeks)	Treatment			
	No	Bonzi	4°C	8°C
Antirrhinum				
0	0	0		
1	0	0	0	1
2	0	0	0	7
3	0	0	3	3
4	0	0	0	0
Dahlia				
0	0	0		
1	0	0	1	0
2	0	0	4	6
3	0	1	3	4
4	0	0	11	6
Impatiens				
0	0	0		
1	0	0	0	0
2	0	0	13	53
3	0	0	82	42
4	0	0	97	75
Marigold				
0	0	0		
1	0	0	0	0
2	0	0	1	3
3	0	0	0	1
4	0	0	1	1
Petunia				
0	0	0		
1	0	0	0	0
2	0	0	0	0
3	0	0	0	1
4	0	1	0	4
Verbena				
0	0	0		
1	0	0	0	0
2	0	0	0	3
3	0	0	1	1
4	0	0	0	6

Similar or increased mortality rates were also noted for all these species when stored at 8°C. This increased loss at 8°C storage may be due to the fact that some species were still active at this temperature and the growth that occurred in the absence of light through the storage period led to a reduction in the carbohydrate reserves within the plug plant. As a result of this lower carbohydrate reserve, the ability of these plugs to recover and survive post transplanting may have been impaired.

Fungal infection occurred on some species during the cold storage treatments, in such cases only healthy plug plants were transplanted into the polystyrene packs. However, the establishment of a fungal disease within the plug tray did appear to have some impact upon plant mortality. Plug plants held at 8°C suffered a higher incidence of disease in store and generally experienced a higher mortality after transplanting. For example, losses were noted from the second week onwards for alyssum stored at 8°C, which coincided with the development of *Sclerotinia* in the plug tray.

However, the direct effect of the storage conditions appeared more significant than disease presence during storage. For example, nemesia plugs stored at 8°C suffered substantial losses of 15% (Week 2), 37% (Week 3), and 83% (Week 4) after transplanting with no recorded incidence of disease during storage. Dahlia, impatiens, lobelia, nemesia and salvia plugs stored at 4°C all suffered losses at some point of over 5% post transplanting, but none of these species suffered from disease during storage. The primary cause of mortality in these species can therefore be attributed to the storage treatment.

With the exception of impatiens, nemesia and possibly dahlia all the plant species survived reasonably well following both cold storage regimes over the four week period. Storage at 8°C produced the highest percentage of losses for the majority of species, with impatiens and nemesia being particularly sensitive. Therefore, storage at 8°C is less likely to be considered in practice. It is also a temperature that is less appropriate for many other applications such as seed storage and so may compromise multiple usage of a cold store facility.

High mortality in stored plugs is a serious loss to the propagator. However, this loss is compounded when seemingly healthy plug plants, which have been chilled or stressed, are transplanted by a grower into retail packs and then subsequently die. The process of replacement due to plant death or poor plant quality is a costly exercise (extra plant material and labour costs and the potential costs of lost business) and leads to a reduction in profitability. This trial highlights the fact that chilled / stressed plugs don't always necessarily immediately show any symptoms of damage especially within the first two weeks of storage.

Plant quality post transplanting

In this study the overall quality of the flowering plants was assessed by leaf colour, plant growth habit and height (details are presented in Appendix 2). There was no evidence that flower form (size and shape) or flower colour was affected by the cold storage regimes.

For each batch of 72 plants transplanted per treatment per week over the four week storage period, a maximum score of 4 was allocated to each individual plant for each characteristic. An average weekly quality score was calculated (Table 5) over a five week period or until all plants within the treatment flowered. Empty spaces within the tables therefore indicate that all plants for that particular treatment had flowered and were no longer being assessed.

Table 5. Quality of the plants after transplanting (mean score of 72 plants; 4 = excellent; 0 = very poor).

Alyssum

Storage	Assessment week														
	Leaf Colour					Habit					Height				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No Treatment															
0	4.0	4.0				4.0	3.9				4.0	3.8			
1	4.0	4.0	3.8			3.9	3.7	3.7			3.7	3.2	3.0		
2	4.0	3.9	3.6			3.6	3.2	3.3			3.1	3.1	2.9		
3	4.0	4.0				3.6	3.7				3.3	3.3			
4	4.0	4.0				3.9	3.9				3.8	3.8			
Bonzi															
0	4.0	4.0				4.0	3.9				4.0	3.9			
1	4.0	4.0	3.8			4.0	4.0	4.0			4.0	3.9	3.7		
2	4.0	3.9	3.9			3.9	3.9	3.9			3.5	3.8	3.6		
3	4.0	3.9				3.9	3.9				3.7	3.9			
4	4.0	4.0				3.8	3.9				3.6	3.7			
4 °C															
0															
1	4.0	4.0	3.8			4.0	4.0	3.9			3.9	3.8	3.5		
2	4.0	3.9	3.8			3.8	3.8	3.8			3.6	3.6	3.6		
3	4.0	4.0	3.9			3.7	3.9	3.8			3.3	3.7	3.6		
4	4.0	4.0	3.8			3.8	3.8	3.8			3.7	3.8	3.8		
8 °C															
0															
1	4.0	4.0	4.0			3.9	3.9	3.9			3.9	3.9	3.9		
2	3.8	3.8	3.5			3.5	3.6	3.5			3.6	3.1	3.1		
3	3.9	3.9	3.9			3.7	3.9	3.8			3.6	3.7	3.7		
4	3.5	3.5	3.4			3.2	3.2	3.2			3.0	3.2	3.1		

Antirrhinum

Storage	Assessment week														
	Leaf Colour					Habit					Height				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No Treatment															
0	4.0	3.9	3.9	3.9	3.9	4.0	3.9	3.9	3.9	3.9	4.0	3.9	3.9	3.9	3.9
1	4.0	4.0	4.0	4.0		3.9	4.0	3.9	4.0		3.9	4.0	3.9	4.0	
2	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0	
3	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0	
4	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0	
Bonzi															
0	4.0	4.0	4.0	4.0	4.0	3.9	3.8	3.9	3.9	4.0	3.9	3.8	3.8	3.8	3.8
1	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		3.9	3.9	3.8	3.8	
2	4.0	4.0	3.8	4.0		3.7	3.8	3.9	4.0		3.8	3.8	3.8	4.0	
3	4.0	4.0	4.0	4.0		3.8	3.8	3.8	3.9		3.9	3.8	3.8	3.9	
4	4.0	4.0	4.0	4.0	4.0	3.8	3.9	4.0	4.0	4.0	3.8	3.8	3.9	4.0	4.0
4 °C															
0															
1	4.0	4.0	4.0	4.0	4.0	3.9	3.8	3.9	4.0	4.0	3.9	3.8	3.9	4.0	4.0
2	4.0	4.0	4.0	4.0	4.0	3.9	3.9	4.0	4.0	4.0	3.9	3.8	3.9	4.0	4.0
3	3.9	3.8	3.5	3.5	3.5	3.6	3.6	3.8	3.8	3.8	3.6	3.6	3.7	3.7	3.7
4	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.9	4.0	4.0	3.9	3.9	3.9	4.0	4.0
8 °C															
0															
1	3.9	4.0	4.0	4.0	4.0	3.9	3.9	4.0	4.0	4.0	4.0	3.9	3.9	4.0	4.0
2	4.0	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.6	3.6	3.7	3.7	3.7
3	3.9	3.9	3.9	3.9		3.8	3.7	3.9	3.9		3.7	3.7	3.9	3.9	
4	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	4.0

Begonia

Storage	Assessment week														
	Leaf Colour					Habit					Height				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No Treatment															
0	3.7	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.8
1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	3.7	3.8
2	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		3.9	3.9	4.0	4.0	
3	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.8	3.8	4.0	4.0	4.0	3.8	3.8
4	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		3.9	3.9	3.8	3.8	
Bonzi															
0	4.0	4.0	4.0	4.0	4.0	3.9	3.9	3.9	4.0	4.0	4.0	3.9	3.9	3.9	4.0
1	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		3.9	3.9	3.9	3.9	
2	3.9	3.9	3.9	3.9	3.9	3.8	3.8	3.8	3.9	3.8	3.8	3.6	3.8	3.8	3.4
3	4.0	4.0	4.0	4.0	4.0	3.9	3.9	4.0	3.9	4.0	3.9	3.9	3.8	3.8	3.9
4	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	3.9	3.9	3.9	
4 °C															
0															
1	4.0	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	4.0	3.9	3.9	4.0	4.0
2	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	4.0	3.8	3.9	4.0	3.8	3.8
3	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.8	3.8	3.9	3.9	4.0
4	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.8	3.7	4.0
8 °C															
0															
1	4.0	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	3.9	3.9	3.8	4.0	3.8
2	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	4.0	3.8	3.9	4.0	3.8	3.8
3	3.9	3.9	3.9	3.9	3.9	3.8	3.8	3.9	3.9	3.9	3.5	3.7	3.5	3.7	3.9
4	4.0	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	3.9	3.9	3.9	3.9	3.8

Dahlia

Storage	Assessment week														
	Leaf Colour					Habit					Height				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No Treatment															
0	4.0	3.9	3.9	3.9	3.9	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.9	4.0	3.9
1	4.0	4.0	3.7	3.8	3.6	4.0	4.0	4.0	4.0	4.0	4.0	3.8	3.8	3.8	3.8
2	4.0	4.0	4.0	3.7	3.8	4.0	4.0	4.0	4.0	4.0	3.9	3.7	3.9	3.8	3.7
3	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.8	4.0	4.0	3.9	4.0
4	4.0	4.0	3.7	3.8	3.8	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.8	3.8	3.8
Bonzi															
0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.9	4.0	4.0	3.9	3.9	3.9	4.0	3.9
1	4.0	4.0	3.8	3.8	3.8	4.0	4.0	4.0	4.0	4.0	4.0	3.8	3.8	3.7	3.8
2	4.0	4.0	4.0	3.8	3.4	3.9	4.0	3.9	4.0	3.9	4.0	3.7	3.7	3.9	3.7
3	3.9	3.9	3.9	3.7	3.8	3.9	3.9	3.9	3.9	3.9	3.7	3.9	3.9	3.7	3.8
4	4.0	4.0	4.0	3.9	4.0	3.9	3.9	4.0	4.0	4.0	3.9	3.9	3.8	4.0	4.0
4 °C															
0															
1	3.9	3.9	3.4	3.6	3.6	3.9	3.9	3.9	4.0	3.9	3.9	3.8	3.8	3.8	3.9
2	3.8	3.7	3.7	3.7	3.6	3.6	3.8	3.8	3.8	3.8	3.6	3.7	3.8	3.7	3.7
3	3.9	3.9	3.9	3.9	3.9	3.8	3.8	3.9	3.9	3.9	3.5	3.8	3.8	3.8	3.8
4	3.6	3.6	3.6	3.6	3.6	3.3	3.5	3.5	3.6	3.6	2.9	3.2	3.5	3.5	3.5
8 °C															
0															
1	4.0	4.0	4.0	4.0	3.8	3.9	4.0	4.0	4.0	4.0	3.9	3.8	3.9	4.0	3.9
2	3.8	3.4	3.6	3.4	3.2	3.3	3.8	3.8	3.6	3.7	3.1	3.5	3.5	3.6	3.4
3	3.8	3.8	3.8	3.8	3.8	3.6	3.8	3.8	3.8	3.8	3.3	3.6	3.6	3.6	3.6
4	3.8	3.8	3.6	3.4	3.1	3.7	3.8	3.8	3.8	3.8	3.6	3.7	3.6	3.4	3.1

Geranium

Storage	Assessment week														
	Leaf Colour					Habit					Height				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No Treatment															
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	4.0
2	4.0	4.0	4.0	3.8	3.8	3.8	4.0	4.0	4.0	4.0	3.8	3.9	3.8	3.7	3.9
3	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.7	3.9	4.0	4.0	4.0
4	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.9	4.0	4.0	4.0
Bonzi															
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	4.0	3.8	4.0	4.0
1	4.0	4.0	4.0	4.0	3.7	4.0	4.0	4.0	4.0	4.0	3.9	3.9	3.9	3.9	3.9
2	4.0	4.0	4.0	4.0	4.0	3.9	3.9	3.9	4.0	4.0	3.9	3.9	3.9	4.0	3.9
3	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.7	3.7	3.7
4	4.0	4.0	4.0	4.0	3.8	3.8	4.0	4.0	4.0	4.0	3.7	3.9	4.0	4.0	3.8
4 °C															
0															
1	4.0	4.0	4.0	4.0	3.7	4.0	4.0	4.0	4.0	4.0	3.9	3.8	3.9	4.0	4.0
2	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.6	3.7	3.9	3.8	3.9
3	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.8	3.8	3.9	3.9	3.9
4	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.8	3.9	3.9	3.7	3.7
8 °C															
0															
1	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.8	3.8	3.8	3.9	3.9
2	3.8	3.8	3.8	3.8	3.4	3.8	3.7	3.7	3.7	3.8	3.3	3.6	3.7	3.7	3.4
3	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4	4.0	3.9	3.9	3.9	3.6	4.0	3.9	3.9	3.9	3.9	3.7	3.8	3.8	3.6	3.6

Impatiens

Storage	Assessment week														
	Leaf Colour					Habit					Height				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No Treatment															
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
1	4.0	4.0	4.0	4.0		4.0	4.0	4.0	3.0		4.0	4.0	4.0	3.0	
2	4.0	4.0	3.7	3.5		4.0	4.0	3.7	4.0		4.0	3.8	3.8	4.0	
3	4.0	4.0	4.0			4.0	4.0	4.0			4.0	4.0	4.0		
4	4.0	4.0				4.0	4.0				4.0	4.0			
Bonzi															
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
1	4.0	4.0	4.0	3.7		4.0	4.0	4.0	3.7		3.9	3.9	3.9	3.8	
2	4.0	3.8	3.8			4.0	4.0	3.8			4.0	3.8	3.8		
3	4.0	4.0	4.0			4.0	4.0	4.0			4.0	4.0	4.0		
4	4.0	4.0				4.0	4.0				4.0	4.0			
4 °C															
0															
1	4.0	4.0	4.0	3.7	3.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.7	3.9
2	3.6	3.5	3.5	3.2	3.1	3.5	3.4	3.5	3.5	3.1	3.4	3.1	3.4	3.3	3.1
3	0.8	0.8	0.7	0.7	0.7	0.1	0.3	0.7	0.6	0.6	0.1	0.4	0.5	0.5	0.6
4	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 °C															
0															
1	4.0	4.0	4.0	4.0	3.5	4.0	4.0	4.0	3.8	3.9	3.9	3.9	4.0	3.8	3.7
2	2.1	1.9	1.9	1.6	1.6	1.1	1.7	1.8	1.8	1.7	1.4	1.4	1.8	1.7	1.7
3	2.7	2.7	2.7	2.7	2.6	2.2	2.6	2.7	2.7	2.6	2.1	2.3	2.7	2.5	2.6
4	1.0	1.0	0.9	0.9	0.9	0.7	0.9	0.9	0.9	1.0	0.6	0.7	1.3	0.8	0.9

Lobelia

Storage	Assessment week														
	Leaf Colour					Habit					Height				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No Treatment															
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0
1	4.0	4.0	4.0	4.0	3.3	4.0	4.0	4.0	4.0	3.3	4.0	4.0	4.0	4.0	4.0
2	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0	
3	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0	
4	4.0	4.0	4.0			4.0	4.0	4.0			4.0	4.0	4.0		
Bonzi															
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
1	4.0	4.0	4.0	4.0	4.0	3.9	3.9	4.0	4.0	4.0	3.9	3.8	4.0	4.0	4.0
2	4.0	4.0	3.8	3.5		4.0	4.0	4.0	4.0		4.0	4.0	4.0	3.5	
3	4.0	4.0	4.0			4.0	3.9	3.9			4.0	3.9	3.9		
4	4.0	4.0	4.0			4.0	4.0	4.0			4.0	4.0	4.0		
4 °C															
0															
1	4.0	4.0	4.0	4.0	3.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.9	3.9
2	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3	4.0	4.0	4.0	3.8	3.7	3.9	3.9	3.9	3.8	3.7	3.9	3.9	3.9	3.8	3.7
4	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	4.0	3.9	3.9	4.0	4.0	4.0
8 °C															
0															
1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2	4.0	4.0	4.0	4.0	3.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3	4.0	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	3.8	3.9	4.0	4.0	4.0
4	3.7	3.7	3.7	3.7	3.4	3.7	3.7	3.7	3.7	3.7	3.6	3.7	3.6	3.4	3.4

Marigold

Storage	Assessment week														
	Leaf Colour					Habit					Height				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No Treatment															
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0
1	4.0	4.0	4.0			4.0	4.0	4.0			4.0	4.0	4.0		
2	4.0	4.0	4.0			4.0	4.0	4.0			4.0	4.0	4.0		
3	4.0	4.0				3.9	4.0				3.8	4.0			
4	4.0	4.0				3.8	4.0				3.9	4.0			
Bonzi															
0	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	3.9	4.0	4.0	
1	4.0	4.0	4.0			4.0	4.0	4.0			4.0	4.0	4.0		
2	4.0	4.0	4.0			4.0	4.0	4.0			4.0	4.0	4.0		
3	4.0	4.0				3.9	4.0				4.0	4.0			
4	4.0	4.0				3.9	4.0				4.0	4.0			
4 °C															
0															
1	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0	
2	3.9	3.9	3.9			3.9	3.9	3.9			3.9	3.9	3.9		
3	4.0	4.0	4.0			4.0	4.0	4.0			4.0	4.0	4.0		
4	3.9	3.9	3.9	3.9		3.9	3.9	3.9	3.9		3.8	3.9	3.9	3.9	
8 °C															
0															
1	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	3.9	4.0	4.0	
2	3.9	3.9	3.9			3.7	3.8	3.9			3.7	3.8	3.9		
3	3.9	3.9	3.9			3.9	3.9	3.9			3.9	3.9	3.9		
4	3.9	3.9	3.9			3.9	3.9	3.9			3.9	3.9	3.9		

Nemesia

Storage	Assessment week														
	Leaf Colour					Habit					Height				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No Treatment															
0	4.0	4.0	4.0	3.9	3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
1	4.0	4.0	3.8	4.0	3.6	3.9	3.9	3.9	3.8	3.8	3.8	3.9	3.7	3.8	3.8
2	3.9	3.9	3.8	3.7	3.7	3.9	3.9	3.9	4.0	3.8	3.9	3.9	3.6	4.0	4.0
3	3.8	3.8	3.8	3.8	3.8	3.6	3.7	3.8	3.8	3.8	3.6	3.7	3.8	3.8	3.8
4	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	4.0
Bonzi															
0	4.0	4.0	4.0	3.9	3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
1	4.0	3.9	3.7	3.7	3.7	4.0	4.0	4.0	3.8	3.8	3.9	3.9	3.9	3.8	3.8
2	4.0	4.0	4.0	4.0	3.8	4.0	4.0	4.0	4.0	4.0	4.0	3.8	3.8	4.0	3.9
3	3.5	3.5	3.5	3.4	3.4	3.5	3.5	3.5	3.5	3.5	3.2	3.3	3.5	3.5	3.4
4	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.8	3.9	3.9	3.9
4 °C															
0															
1	4.0	4.0	4.0	3.9	4.0	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	4.0
2	4.0	4.0	4.0	3.8		3.9	3.9	3.8	3.8		3.9	4.0	3.8	3.8	
3	3.8	3.8	3.8	3.8		3.8	3.8	3.8	3.8		3.5	3.8	3.8	3.8	
4	3.8	3.8	3.8	3.8		3.7	3.8	3.8	3.8		3.4	3.7	3.7	3.8	
8 °C															
0															
1	4.0	4.0	3.9	3.8	3.6	4.0	4.0	3.9	3.8	3.6	4.0	4.0	3.9	3.8	3.7
2	3.4	3.4	3.4	3.4	3.3	2.7	3.3	3.4	3.4	3.3	3.4	3.0	3.0	3.3	3.3
3	2.5	2.5	2.5	2.5	2.5	2.0	2.3	2.5	2.5	2.5	2.0	2.2	2.5	2.4	2.5
4	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	1.8	0.6	0.6	0.7	0.7

Petunia

Storage	Assessment week														
	Leaf Colour					Habit					Height				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No Treatment															
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.8	3.8	4.0
1	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	3.9	3.8	3.9	
2	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0	
3	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0	
4	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		3.9	4.0	4.0	4.0	
Bonzi															
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
1	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0	
2	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	3.8	3.8	3.8	
3	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		3.8	3.8	4.0	4.0	
4	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
4 °C															
0															
1	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	3.8	3.9	4.0	
2	4.0	4.0	3.8	3.8		4.0	4.0	4.0	4.0		4.0	3.8	3.8	3.7	
3	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	3.9	4.0	4.0	
4	4.0	4.0	3.7	3.5		4.0	4.0	4.0	4.0		3.8	3.8	3.8	3.8	
8 °C															
0															
1	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	3.9	4.0	4.0	
2	4.0	4.0	3.7	3.8		4.0	4.0	4.0	4.0		4.0	4.0	4.0	3.8	
3	3.9	3.9	3.9	3.9		3.9	3.9	3.9	3.9		3.9	3.9	3.9	3.9	
4	3.8	3.8	3.6	3.4		3.8	3.8	3.8	3.8		3.6	3.7	3.5	3.7	

Salvia

Storage	Assessment week														
	Leaf Colour					Habit					Height				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No Treatment															
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
1	4.0	4.0	4.0	4.0	3.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2	3.9	3.9	3.8	3.6	3.7	3.9	3.9	3.9	3.9	3.8	3.9	3.9	3.9	3.9	3.9
3	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0	
Bonzi															
0	4.0	4.0	4.0	3.8	3.8	4.0	4.0	4.0	4.0	3.8	4.0	4.0	4.0	4.0	4.0
1	4.0	4.0	3.8	3.8	3.7	3.9	3.9	3.9	3.8	3.8	4.0	3.9	3.9	3.9	3.9
2	4.0	4.0	3.7	3.5	3.3	4.0	4.0	4.0	4.0	3.5	4.0	4.0	4.0	4.0	3.9
3	3.9	4.0	4.0	4.0	4.0	3.9	4.0	4.0	3.9	4.0	3.9	4.0	4.0	4.0	4.0
4	3.9	3.9	3.9	3.9		3.9	3.9	3.9	3.9		3.9	3.9	3.9	3.9	
4 °C															
0															
1	4.0	4.0	3.8	3.8	3.5	4.0	4.0	4.0	3.8	4.0	4.0	4.0	3.8	4.0	4.0
2	4.0	4.0	3.8	3.5	3.0	3.9	3.9	4.0	4.0	3.6	3.9	3.9	4.0	4.0	3.7
3	3.8	3.8	3.8	3.8	3.8	3.7	3.8	3.8	3.8	3.8	3.6	3.7	3.8	3.8	3.8
4	3.8	3.8	3.8	3.2	2.3	3.1	3.4	3.1	2.9	3.0	3.1	3.3	3.1	3.0	2.8
8 °C															
0															
1	4.0	4.0	4.0	3.8	3.7	4.0	4.0	4.0	3.7	4.0	4.0	4.0	4.0	3.7	3.8
2	4.0	4.0	3.8	3.5	3.0	3.9	3.9	4.0	3.5	3.2	3.9	3.9	4.0	3.5	3.7
3	3.7	3.7	3.7	3.6	3.7	3.3	3.4	3.6	3.7	3.7	3.1	3.4	3.6	3.7	3.7
4	3.9	3.7	3.4	3.4	2.9	3.3	3.5	3.6	3.6	3.2	3.3	3.5	3.4	3.3	3.2

Verbena

Storage	Assessment week														
	Leaf Colour					Habit					Height				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No Treatment															
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2	4.0	4.0	4.0	3.8	3.5	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	3.8	3.6
3	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Bonzi															
0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9
1	4.0	4.0	4.0	4.0	3.8	3.9	3.9	3.9	3.8	3.8	3.9	3.9	3.9	3.9	3.9
2	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.8	4.0
3	4.0	4.0	4.0	3.7	3.9	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	3.7	3.9
4	4.0	4.0	4.0	4.0	4.0	3.9	4.0	4.0	4.0	4.0	3.9	4.0	3.8	3.8	3.8
4 °C															
0															
1	4.0	4.0	4.0	4.0	3.8	4.0	4.0	3.8	3.8	4.0	4.0	4.0	3.8	3.8	4.0
2	4.0	4.0	4.0	3.7	3.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.8
3	3.9	3.9	3.9	3.9	3.9	3.8	3.9	3.9	3.9	3.9	3.6	3.8	3.9	3.9	3.9
4	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.8	3.8	3.8	3.8
8 °C															
0															
1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.8	4.0
2	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.8	3.9	3.9	3.9	3.9
3	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.8
4	3.8	3.8	3.8	3.8	3.6	3.7	3.7	3.8	3.8	3.8	3.5	3.5	3.8	3.8	3.6

Figure 4. Example of lobelia plugs of marketable out of store quality, then one and three weeks after transplanting

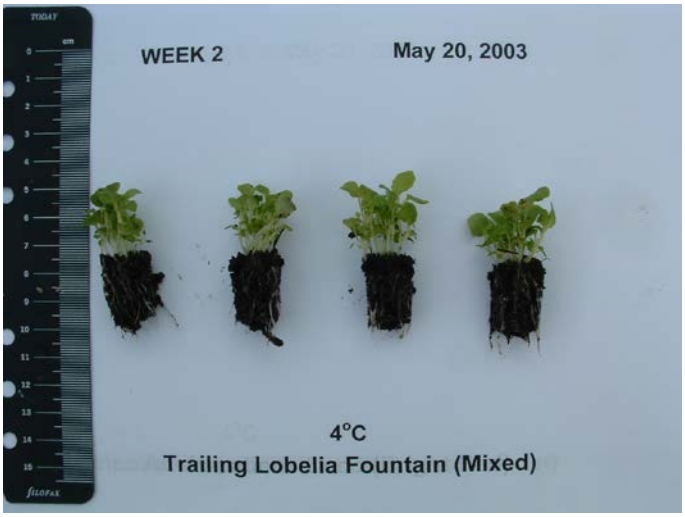


Figure 5. Example of nemesia plugs of acceptable out of store quality, then one and three weeks after transplanting

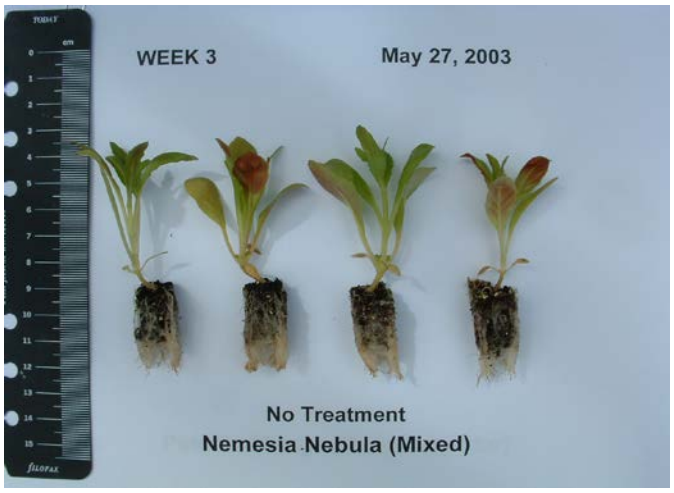
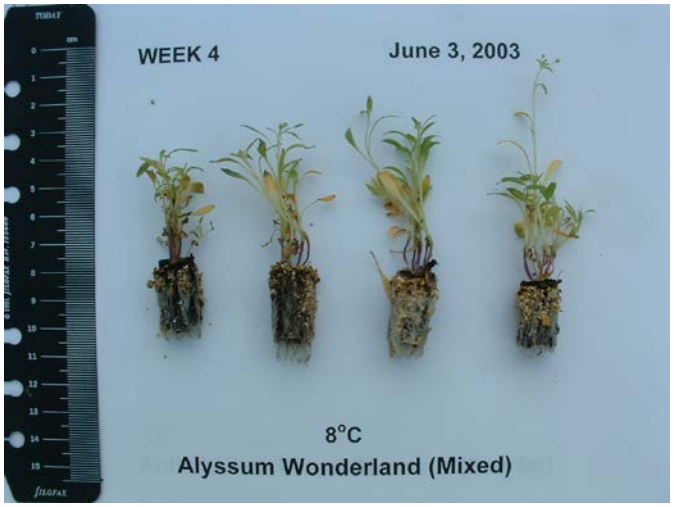


Figure 6. Example of alyssum plugs of poor out of store quality, then one and three weeks after transplanting



The most frequent symptoms recorded immediately post transplanting that led to reductions in the quality score allocated were:

- leaf paleness following longer periods of cold storage in the dark
- leaf nutrient deficiency symptoms following longer periods of storage in the glasshouse
- stem or leaf petiole stretching
- variability in overall plant habit
- lower leaf yellowing

An average score of 3.0 or above was considered to be a plant of acceptable marketable quality. Plants with a quality score below 3.0 have been highlighted in the tables for ease of identification. This quality score has been taken as the minimum level of acceptability for producing recommendations for storage of bedding plant plugs.

For the majority of plant species, plugs transplanted into packs developed into plants which were at least of acceptable quality if not higher, irrespective of the storage method. The key exceptions to this were cold stored impatiens and nemesia. After one weeks storage at 8°C or two weeks storage at 4°C, impatiens plug quality had declined so much that the plants never recovered after transplanting. Plants either died or remained of poor quality throughout the trial. In the case of nemesia, a similar situation occurred with plug plants stored at 8°C for three weeks or more.

Longer periods of storage, usually in excess of two or three weeks, also reduced initial plug quality and this had an effect on final plant quality, although in most cases final plant quality was still acceptable (Figures 4-6). This deterioration was mainly noted with cold stored plugs, for example dahlia, impatiens, marigold, nemesia and salvia stored at both 4°C and 8°C and alyssum, petunia and verbena stored at 8°C.

For most species, plant quality post transplanting was maintained throughout the assessment period, on a number of occasions a reduction in plant quality was noted over time whilst conversely on the odd occasion quality improved slightly with time.

Time to first flower and full flower post transplanting

The week in which flower colour was first noted, post transplanting, for each treatment was recorded and is shown in Table 6 (first flower). The week in which all the plants in each treatment flowered was also recorded and is also shown in Table 6 (full flower). Assessments for flowering were performed for a total of eleven weeks, where plants such as dahlia and geranium took a longer period of time to come into flower, the week in which full flower occurred was often outside this period and was therefore not precisely recorded. Glasshouse temperatures, recorded using a shaded data logger, for the full period of the trial are presented in Appendix 3.

Time to first and full flower was species dependent, however most of the plant species attained full flower within five weeks of transplanting. An effect of cold storing the plugs in the dark on the time to first and full flower was noted for all species in the trial.

In the case of plugs stored in the glasshouse on benches (no treatment control and Bonzi treatment), the number of weeks the plants took to both come into flower and attain full flower declined in relation to the number of weeks the plugs were held. This was because the plugs

Table 6. The week to first flower for the plants in each treatment and the week to full flower for all plants in each treatment after transplanting

Storage (weeks)	Treatment							
	No		Bonzi		4°C		8°C	
Alyssum	1st	Full	1st	Full	1st	Full	1st	Full
0	1	2	1	2				
1	1	3	1	3	1	3	1	3
2	1	3	1	3	1	3	1	3
3	1	2	1	2	1	3	2	3
4	1	2	1	2	1	3	2	3
Begonia								
0	3	5	3	5				
1	3	5	3	4	3	5	2	5
2	2	4	2	5	3	5	2	5
3	2	5	2	5	2	6	2	6
4	1	4	1	4	3	5	3	5
Geranium								
0	8	>11	8	11				
1	7	10	7	10	8	10	8	10
2	7	>9	7	>9	7	9	7	9
3	7	>8	7	8	7	>8	7	8
4	7	>8	6	>7	7	>7	7	>7
Lobelia								
0	5	6	5	6				
1	4	5	4	5	4	5	5	6
2	3	4	2	4	4	5	4	5
3	3	4	2	3	4	5	4	5
4	1	3	1	3	4	5	5	5
Nemesia								
0	4	5	4	5				
1	3	5	3	5	4	5	4	5
2	3	5	3	5	3	4	4	5
3	2	5	2	5	3	4	3	5
4	1	5	1	5	3	4	4	5
Salvia								
0	4	5	4	5				
1	3	5	4	5	4	5	4	5
2	3	5	3	5	4	5	4	5
3	3	5	2	5	3	5	4	5
4	3	4	3	4	4	7	4	6

Storage (weeks)	Treatment							
	No		Bonzi		4°C		8°C	
Antirrhinum	1st	Full	1st	Full	1st	Full	1st	Full
0	4	5	4	5				
1	3	4	4	4	4	5	4	5
2	3	4	3	4	4	5	4	5
3	2	4	2	4	4	5	4	4
4	1	4	1	5	4	5	4	5
Dahlia								
0	6	>11	6	>11				
1	5	>10	6	>10	6	>10	6	10
2	5	>9	6	>9	7	>9	7	>9
3	4	>8	5	>8	6	>8	7	>8
4	4	>7	4	>7	7	>7	7	>7
Impatiens								
0	5	5	5	5				
1	4	4	3	4	4	5	4	5
2	3	4	3	3	4	6	4	6
3	2	3	2	3	5	7	4	6
4	1	2	1	2	6	7	4	6
Marigold								
0	3	5	3	4				
1	3	3	3	3	3	4	3	4
2	2	3	2	3	2	3	2	3
3	1	2	1	2	2	3	2	3
4	1	2	1	2	2	4	1	3
Petunia								
0	4	5	4	5				
1	3	4	3	4	4	4	3	4
2	2	4	2	4	3	4	2	4
3	2	4	2	4	3	4	3	4
4	1	4	1	5	3	4	3	4
Verbena								
0	5	6	4	6				
1	3	6	3	6	4	6	3	6
2	3	6	3	6	4	6	3	5
3	2	6	2	6	3	6	3	6
4	1	5	1	5	3	6	3	5

and plants were exposed to natural day length, light levels and glasshouse temperatures and therefore flower initiation could occur at the natural time in response to day length. As the season progressed and temperatures and day lengths increased, plant development rates also increased reducing the time taken to flower. The main exception to this was alyssum, this species began flowering as a plug soon after delivery and before storage commenced. Flowers were therefore recorded immediately after transplanting irrespective of how many weeks the plugs had been held in the glasshouse.

The cold storage regimes halted flower initiation and / or development for all plant species. It may be that storing the plugs in the dark prevented flower initiation from occurring or that the low temperatures prevented further flower development (initiation having occurred prior to storage). Whatever the reason, flower development did not progress until the plugs were taken out of cold store. Therefore, the time to first flower and full flower for plug material that was cold stored, irrespective of the storage period, was often directly comparable to the flowering times taken for the plant material transplanted at the beginning of the trial prior to any storage (week 0). Antirrhinum is a clear example of this, with the first flower occurring after four weeks, and full flower after five weeks for plugs transplanted on arrival. These time periods are exactly the same for each set of plugs removed from cold store over the four week storage period (Table 6).

In the case of alyssum a slight delay in time to first flower was noted from the third week onwards for plug material stored at 8^{o}C, flowering did not occur until the second week after transplanting (as opposed to the first week for the other storage treatments). This possibly indicates that flower death or bud abortion occurred in cold store resulting in a delay in flowering.

A delay in the time to full flower was also noted in the case of salvia for plug plants stored longer than three weeks. This was a result of apical growing point death and the extra time required for flower bud development to occur in the side shoots.

Storage summary by plant species

Alyssum

A higher mortality rate occurred for this species post transplanting when the plugs were stored for longer than a week at 8^{o}C. *Sclerotinia* also established on the plugs in the tray at 8^{o}C. When the plugs were stored at 4^{o}C, plug quality out of store was higher and no plant loss occurred post transplanting (Tables 3 and 5), indicating alyssum stored better at the lower storage temperature.

The alyssum plugs began to flower in the plug trays soon after delivery, therefore many of the plugs had already formed buds before the storage treatments commenced. This resulted in plants flowering in the first week after transplanting (Table 6). For plugs stored over two weeks at 8^{o}C, flowering did not occur until the second week after transplanting. This may indicate that flower death or bud abortion occurred in store resulting in a slight delay in flowering.

Some of the plugs transplanted out of store were of variable quality, with the primary source of loss of quality occurring for height (plugs were stretched), variable habit and lower leaf yellowing (Figure 4, alyssum). However, final plant quality was still of an acceptable level (over 3.0) for the finished product with the majority of storage treatments.

Antirrhinum

Antirrhinum were tolerant of all the storage regimes. Some plant loss, post transplanting, did occur for cold stored plugs, with the highest mortality of 7% occurring after two weeks storage at 8^{o}C.
Although the plug plants were small at the start of the trial, those stored in the glasshouse rapidly developed into tall plugs, flowering within four to five weeks of the start of the trial whether they were immediately potted or stored for four weeks (Table 6). Cold storage halted both vegetative growth and flower development. Plugs from cold store were still small when transplanted into packs. However, following transplanting growth and flower development rapidly resumed resulting in first flower colour after four weeks and full flower after five weeks, irrespective of time in store.

Begonia

Begonia plugs were extremely tolerant of all the storage regimes, with no major losses occurring in response to any of the storage treatments. Plugs stored under all the treatments were still acceptable after three to four weeks of storage (Figure 7). The only losses in quality were minor reflecting the pale leaf colour in some of the stored plugs. All treatments produced a high quality finished product.

The flowering response observed in begonia was similar to that of antirrhinum, where plugs stored in the glasshouse continued to develop, resulting in the first flower being produced in relation to the number of weeks from the start of the trial, irrespective of the storage period (Table 6). The cold store temperatures halted growth and flower development. After being placed in the glasshouse, growth and flower development resumed resulting in first flower colour two to three weeks after transplanting, and full flower after five or six weeks; one week longer than plugs stored in the glasshouse.

Dahlia

Dahlia plugs stored well in the glasshouse and were still acceptable after four weeks of storage, with only limited stretching of the plug plants. However, they did not hold as well in cold storage, resulting in losses during in storage. Although surviving plugs seemed to be of good quality, following transplanting, plant mortality continued to occur for plugs that had been stored for over two weeks in cold storage.

The quality of the cold stored plugs was not consistent, with some plants growing well after transplanting whilst others did not, resulting in low uniformity within some packs (Table 5). Flowering time was not uniform, resulting in only some of the plants flowering within the assessment period, however this may be a reflection of the mixed flower colours within this variety.

Geranium

Geranium plugs tolerated all the storage regimes and were still generally acceptable after four weeks of storage (Figure 8). *Botrytis* infection of the lower senescing foliage was noted on plugs in cold store. Some losses post transplanting did occur after two weeks storage at 8^{o}C (6%). Plugs that were stored in the glasshouse suffered from minor losses in quality following transplanting due to reddening of the foliage (nutrient deficiency) and some stretching. All the

storage treatments produced a high quality finished product, which began flowering six to eight weeks after transplanting.

Impatiens

Cold stored impatiens plugs suffered from high mortality (Figure 9) both in store and following transplanting after only one to two weeks of storage. Plugs stored in the glasshouse remained of an acceptable quality for up to three weeks, although flower buds had formed by this period. No plant mortality occurred for plugs stored in the glasshouse.

The flowering response for plugs stored in the glasshouse was again similar to that of many other species, and coincided with exposure to day length, light levels and temperature. As with other plant species, cold storage halted flower initiation and / or development for the period of storage. Time to full flower for plugs kept in cold storage for longer periods of time was delayed by one to two weeks. This effect was due to the high mortality rate experienced as a result of these treatments, generally only two to three plants survived in each pack. As a result, there was no competition for light between the surviving plants, which spread across the available surface of the pack and remained in a vegetative state for a longer period of time.

Long term cold storage of impatiens (at either 4°C or 8°C) is not a feasible option as the plugs suffered unacceptably high mortality rates in store and post transplanting and the plants produced were of poor quality. Plugs stored in the glasshouse however, produced high quality marketable plants.

Lobelia

Lobelia tolerated all the storage treatments reasonably well. Low losses, post transplanting, were observed at 4°C (three weeks – 7% losses) and 8°C (four weeks – 7% losses). *Botrytis* was observed colonising damaged tissue on the plugs stored at 8°C after four weeks. Cold storage did not affect the quality of lobelia to any great extent, except for reducing the leaf colour intensity after three weeks of storage. Storage in the glasshouse however, resulted in stretched plugs by the third week.

The flowering response was similar to that of antirrhinum and other species, the plugs stored in the glasshouse flowered in response to day length, light levels and temperature. Cold storage halted flower initiation and / or development for the period of storage (Table 6).

Marigold

Plugs stored in the glasshouse maintained reasonable quality for three to four weeks, however by the second to third week the plugs had become stretched, flower buds had developed in the growing point of each plug and nutritional deficiency symptoms were evident (leaf tip bronzing). Plugs stored at 4°C or 8°C suffered leaf tip necrosis and chlorophyll degradation (leaf paling) by the second week and there was some stem etiolation. At 8°C both *Botrytis* and *Sclerotinia* were noted on the plugs. The presence of these diseases may have resulted in minor losses after transplanting. Plants post transplanting were of a high, uniform marketable quality.

Nemesia

Nemesia plugs held in cold store at 8°C suffered high rates of mortality towards the end of the storage period. Surviving plugs that were transplanted into trays also suffered from high mortality rates. For plugs stored at 4°C however no major plug death was noted and only 6% mortality occurred after transplanting, for plugs stored for four weeks.

Plugs stored at 4°C were pale and stretched, but were of acceptable quality up until the second or third week (Figure 10). Plugs stored in the glasshouse were still of an acceptable quality after a similar period of storage, but nutritional deficiency symptoms had become obvious (pale, bronzed foliage). A post transplanting mortality rate of 12% was noted for nemesia plugs held in the glassshouse for 3 weeks and treated weekly with Bonzi.

The flowering response noted for nemesia was similar to that noted for the other plant species. In the case of plugs stored in the glasshouse, flowering was determined by exposure to day length, light levels and temperature. This resulted in a steady reduction in the time to first flower as the storage period increased. Cold storage in the dark, halted flower initiation and / or development until the plugs were brought out of store. This resulted in an almost consistent time to first and full flower irrespective of the storage period. The quality of the finished product was reasonably high for all the treatments, apart from plugs stored at 8°C for over a week.

Petunia

Plugs held in all the storage treatments were acceptable for a minimum of three weeks. By this time the foliage on the plugs stored in the glasshouse had began to purple whilst the foliage on the cold stored plugs became pale (due to chlorophyll breakdown) and petiole etiolation was evident.

Botrytis occurred on the plugs after two weeks of storage at 8°C, and continued to develop leading to a significant infection after four weeks. Only a limited level of *Botrytis* occurred after four weeks at 4°C. Plug mortality post transplanting was low in the case of all treatments, with the highest losses (4%) observed for the 8°C storage treatment, possibly reflecting the *Botrytis* infection. Following transplanting, all the plants regardless of treatment were of high marketable quality.

Salvia

Salvia plugs remained acceptable for all the storage treatments up to the third week. Plug death and leaf necrosis was noted for cold stored plugs by the fourth week. Some plant loss, post transplanting, occurred for cold stored plugs held in excess of two weeks (Table 4). Plant quality post transplanting for plugs held in cold storage for over two weeks was also slightly lower. This was due to leaf / shoot death in the growing point of the plants. This resulted in plants receiving lower scores for the intensity of leaf colour, plant habit and height. The longer the plugs were held in store, the more severe the damage became, with four week cold stored plugs just making an acceptable finished product. The development of flower buds in the side shoots as opposed to the 'chilled' apical growing point delayed the time to full flower for plugs stored for four weeks in cold storage.

Verbena

Botrytis was observed on verbena plugs stored at 8°C after two weeks and 4°C after four weeks. Plugs from all the storage treatments were acceptable after three weeks of storage, however, leaf tip necrosis, stem stretching and loss of leaf colour occurred after four weeks of cold storage. Plant mortality, post transplanting, increased after four weeks of storage at 8C (6%) coinciding with the *Botrytis* infection noted in store.

The flowering response noted in the verbena plants was similar to that noted in the other plant species. A reduction in time to first flower with increasing storage period for plugs stored in the glasshouse, whilst flower initiation and / or development was halted during the period of cold storage. Plant quality post transplanting was uniformly high in response to all the treatments.

Figure 7. Begonia plugs maintaining good quality over time (8°C storage)

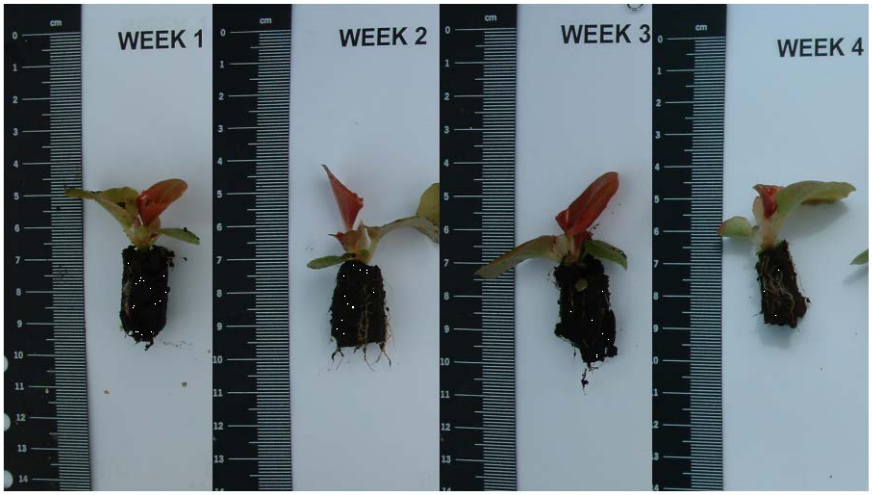
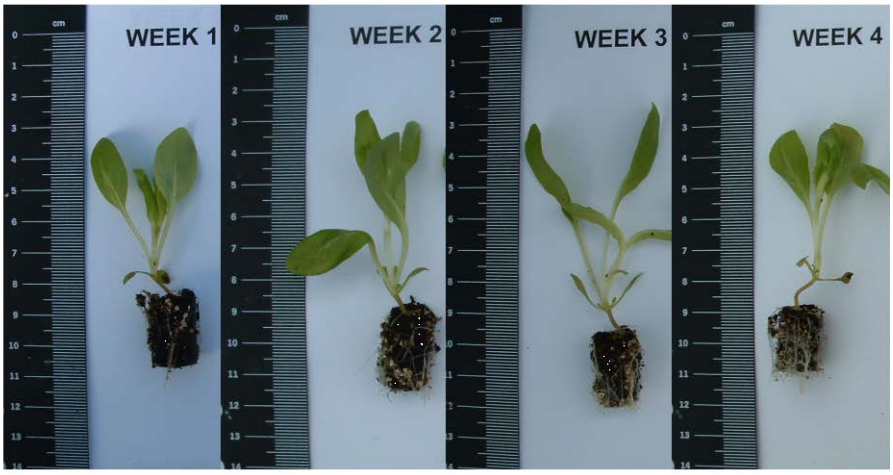


Figure 8. Geranium plugs showing degradation during storage (8°C storage)

Figure 9. Impatiens plugs showing chilling injury from week 3 (4°C storage)

Figure 10. Nemesia plugs showing leaf petiole etiolation (4°C storage)



Conclusions

The results from the trial highlight the importance of careful plug management even if the plugs are only held in a glasshouse. Placing plug trays on the floor or bench of a glasshouse, as opposed to leaving them on a Danish trolley, and carefully watering and feeding them substantially extends the shelf life of the plugs. As can be seen from the results, holding plugs to an acceptable quality level can be attained for up to three to four weeks with some bedding plant species.

The trial indicated that there is potential for the cold storage of bedding plant plugs, the results generated by this study broadly correlate with those generated by previous work carried out in the USA (Heins *et al*., 1992 and 1995 and Kaczperski and Armitage, 1992).

The study highlighted two ways in which cold storage might be used if production space is limited. Firstly, storage of plugs destined for direct sale. The trial results show that to maintain the necessary quality, plugs raised for commercial sale should be stored for the minimum period only in cold store. In the case of most of the plant species examined in the trial the maximum storage period was 7 days at 4^{o}C. In the case of a small number of plant species (for example begonia, lobelia and antirrhinum) this period could possibly be extended to 14 days. In the case of impatiens plugs, very short term storage should only be considered or possibly storage at a higher temperature attempted.

The trial also highlighted the effects of the cold storage regime on plant quality and mortality rate post transplanting. In the case of a few plant species, plug damage and death was not noted during storage, but plant death post transplanting was a serious issue. For example, nemesia plugs stored for two weeks at 8^{o}C and impatiens stored for two weeks at 4^{o}C suffered large losses post transplanting before losses in store became noticeable. Salvia plugs cold stored for longer than two to three weeks also suffered a loss in quality post transplanting due to growing point death and leaf necrosis. This is a serious issue for any commercial propagator wishing to use cold storage, because plugs may look of an acceptable quality at dispatch but by the time they have been delivered or even transplanted by the customer large losses may have occurred.

Secondly, the technique may be used to store plugs prior to transplanting to produce finished plants. In this scenario, out of store plug quality does not have to be as high, because it is finished plants rather than plugs that are being sold. In this case the trial demonstrated that plugs could be held for longer periods of time (up to three or four weeks) if a short term drop in quality could be accommodated. This loss of quality usually equated to a loss of leaf colour intensity, lower leaf yellowing and slight internode extension. The trial also indicated that plugs of a lower quality still produced quality finished plants if managed carefully.

Observations made during the trial also address other practical issues:

- As an average storage temperature, 4^{o}C appeared more appropriate than 8^{o}C. The warmer regime allowed the continued development of many of the plant species (albeit slowly) in cold store resulting in pale, stretched plugs after several weeks of storage in the dark.

- The 8^{o}C cold storage regime also permitted the more rapid development of diseases such as *Botrytis* on damaged or senescing plant tissue.

Table 7. Recommended maximum cold storage periods for a range of bedding plant plugs

	4°C storage		8°C storage	
Species	***Commercial plug quality****	***Acceptable quality plug•***	***Commercial plug quality****	***Acceptable quality plug•***
Alyssum	7 days	14 days	7 days	7-14 days
Antirrhinum	14 days	21-28 days	7-14 days	21-28 days
Begonia	14 days	21-28 days	7-14 days	21-28 days
Dahlia ∇	7 days	21 days	7 days	14-21 days
Geranium	7-14 days	28 days	7 days	21 days
Impatiens ∇	0-7 days	0-7 days	0-7 days	0-7 days
Lobelia	14 days	28 days	7-14 days	21-28 days
Marigold	14 days	21-28 days	14 days	21-28 days
Nemesia ∇	7 days	14 days	7 days	14 days
Petunia	7-14 days	21 days	7 days	21-28 days
Salvia ∇	7 days	21 days	7 days	14-21 days
Verbena	7-14 days	21 days	7 days	14-21 days

∇ Severe to moderate chilling injury noted with these subjects.
* plugs for direct sale
• plugs held prior to transplanting

- The choice of cold store and management of the plugs in store is vital. A store with good air circulation reduces the risk of high humidities building and diseases becoming established. However, too much air movement dries out plugs necessitating a frequent irrigation programme.

- Frequent checks on plugs in store are needed to monitor quality levels and assess potential disease problems. Appropriate fungicide spray programmes need to be in place if necessary, one-off treatments are limited in their effect.

- A low level of light (in the range of 1μmol m^{-2} s^{-1}) may help to prevent etiolated plant growth (Heins *et al*., 1992 and 1995), especially if storage temperatures are sub-optimal and there is a risk of plant growth in store.

- The information generated could also be extrapolated to develop suitable storage regimes for the transportation of bedding plant plugs to maintain quality without causing chilling injury.

Technology Transfer

The following technology transfer activities relate to the project:

- An open day was held at Writtle College on the 11 June 2003. A presentation on the possibility of cold storing bedding plugs was made and visitors were able to see the facilities at Writtle and view the trial in progress.

- An interim report (literature review) was submitted to the HDC September 2003.

- An article was prepared for the February 2004 issue of the HDC News summarising the results of the trial.

- A summary of the trial was presented at the HDC Bedding Plant Open Day held at HRI Wellesbourne on 12 February 2004.

- The final report was submitted to the HDC March 2004.

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Kaczperskia, M.P. and Armitage, A.M. (1992) Short term storage of plug grown bedding plant seedlings. HortScience. 27 (7): 798-800.

Styer, R.C. and Koranski, D.S. (1997) Plug and transplant production: a growers guide. Ball Publishing: Illinois.

Appendix 1. Disease assessment of plugs after two and four weeks in cold storage

2 weeks storage at 4°C

Alyssum	No disease evident
Antirrhinum	No disease evident
Begonia	No disease evident
Dahlia	No disease evident
Geranium	First signs of *Botrytis* on lower foliage
Impatiens	No disease evident
Lobelia	No disease evident
Marigold	No disease evident
Nemesia	No disease evident
Petunia	No disease evident
Salvia	No disease evident
Verbena	No disease evident

2 weeks storage at 8°C

Alyssum	*Sclerotinia* established on an area of plants
Antirrhinum	No disease evident
Begonia	Some *Botrytis* on damaged plant tissue
Dahlia	No disease evident
Geranium	*Botrytis* on lower foliage
Impatiens	First signs of *Botrytis* on damaged plant tissue
Lobelia	Some *Botrytis* on damaged plant tissue
Marigold	Some *Botrytis* on damaged plant tissue and an area of *Sclerotinia*
Nemesia	No disease evident
Petunia	First signs of *Botrytis* on damaged plant tissue
Salvia	No disease evident
Verbena	First signs of *Botrytis* on damaged plant tissue

4 weeks storage at 4°C

Alyssum	No disease evident
Antirrhinum	No disease evident
Begonia	No disease evident
Dahlia	No disease evident
Geranium	Some *Botrytis* on lower foliage
Impatiens	No disease evident (even on dying plant material)
Lobelia	No disease evident
Marigold	No disease evident
Nemesia	No disease evident
Petunia	Odd area of *Botrytis*
Salvia	No disease evident
Verbena	Some *Botrytis* on damaged plant tissue

4 weeks storage at 8°C

Alyssum	Area of *Sclerotinia* still evident
Antirrhinum	No disease evident
Begonia	Some *Botrytis* on damaged / senescing plant tissue
Dahlia	*Botrytis* on dead plants / foliage
Geranium	Significant amount of *Botrytis* on lower foliage
Impatiens	Almost all dead (chilling injury)
Lobelia	*Botrytis* on damaged plant tissue
Marigold	Area of *Sclerotinia* still evident
Nemesia	Almost all dead (chilling injury)
Petunia	Significant areas of *Botrytis*
Salvia	*Botrytis* on dead plants / foliage
Verbena	Low level of *Botrytis*

Appendix 2. Plant quality scores post transplanting

Leaf colour

4 Excellent colour, no leaf necrosis or chlorosis visible.
3 Acceptable colour, very minor necrosis or chlorosis.
2 Noticeable necrosis (due to damage or disease) or chlorosis (yellowing of foliage due to lack of light or nutrient availability).
1 Overall poor appearance due to necrosis or chlorosis.
0 Unacceptable high levels of necrosis or chlorosis.

Habit

4 Excellent plant structure, healthy vigorous growth.
3 Acceptable structure, strong growth with no noticeable defects.
2 Slightly poor plant structure, with noticeably weak growth or growth defects.
1 Poor plant structure with weak growth or defects highly noticeable.
0 Unacceptable poor plant structure.

Height

4 No stem stretching. Very uniform plant height for all plants in the pack.
3 Acceptable plant height, with very minor variation in plant height within the pack. No evidence of stem stretching.
2 Slight stem stretching, variation in plant height evident within the pack.
1 Stretched growth noticeable, high level of variability in plant height within the pack.
0 Unacceptable level of stretching. Very high level of variability in height within the pack.

Appendix 2. Examples of quality score assessments

Score – 0 (plant death)

Score – 1 (poor uniformity / stunting evident)

Score – 1 (plants stunted / chlorotic)

Score – 2 (poor uniformity)

Appendix 2

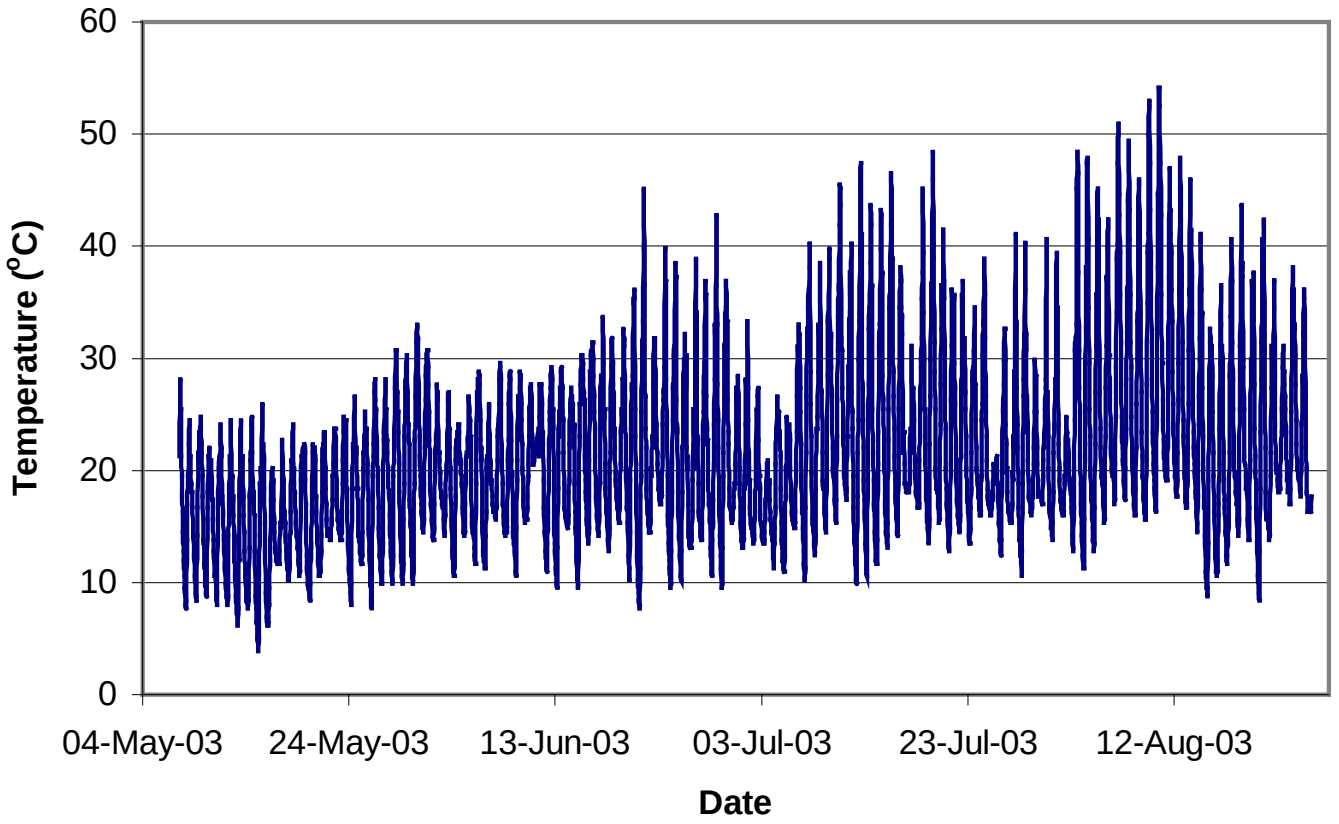
Score – 3 (slight unevenness)

Score – 4 (uniform quality plants)

Score – 4 (uniform quality plants)

Score – 4 (uniform quality plants)

Appendix 3. Glasshouse temperatures over the period of the trial



Appendix 4. Bedding plant plugs after two and four weeks of storage

Alyssum

Impatiens

2 weeks storage in the glasshouse

Marigold

Nemesia

Appendix 4

Antirrhinum

Petunia

2 weeks cold storage at 4°C

Begonia

Dahlia

Appendix 4

Impatiens

Nemesia

2 weeks cold storage at 8^{o}C

Verbena

Petunia

Appendix 4

Salvia

Nemesia

4 weeks storage in the glasshouse

Antirrhinum

Alyssum

Appendix 4

Begonia

Lobelia

4 weeks cold storage at 4^{o}C

Petunia

Alyssum

Appendix 4

Begonia

Lobelia

4 weeks cold storage at 8^{o}C

Geranium

Marigold