PC 234
Bedding Plants:
Benchmarking current transport and distribution practices with the aim of identifying factors that determine plant quality during transit and methods to maintain quality

R. Cameron, J. Wagstaffe,
A. Kearton, W. Brough
& A. Davis

University of Reading
ADAS

Year 2 Report

Project Title	Bedding plants: Benchmarking current transport and distribution practices with the aim of identifying factors that determine plant quality during transit and methods to maintain quality.
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Key staff:	R. Cameron - Reading J. Wagstaffe- Reading A. Kearton - ADAS W. Brough - ADAS A. Davis
Location of project:	University of Reading and various Nurseries, Retail Warehouses and Garden Centres
Project coordinator:	Alan Davis, Appletree Lodge, Shepherds Lane, Chard, Somerset. TA20 1QU
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The results and conclusions in this report are based on a series of experiments conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

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

[Ross Cameron]
[Researcher]
[Centre for Horticulture and Landscape,
University of Reading]

Signature .... Date ....

[Wayne Brough]
[Advisor]
[ADAS]

Signature .... Date ....

[Alan Davis]
[Independent Consultant]

Signature .... Date ....

Report authorised by:

[Name]
[Position]
[Organisation]

Signature .... Date ....

[Name]
[Position]
[Organisation]

Signature .... Date ....

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Grower Summary

Headlines

- Storage duration (length of transportation ‘run’) appeared the most critical factor influencing bedding plant quality, with injury evident in a range of crops after 48 hours.
- Loss of quality could also occur after 24 hours, but usually only when there was an additional negative factor such as relatively high storage temperature (22ºC).

Background and expected deliverables

Loss of quality of bedding plants can occur during the transport and retail chain, but the extent to which transport conditions contribute to loss of quality in bedding plants is largely undetermined. The retailing of poor quality plants can undermine consumer confidence and loyalty to a particular garden centre or retail outlet. Similarly, the rejection of a crop not only results in the loss of a single sale for the grower, but again undermines the reputation of that nursery and in the worst cases can lead to legal action. The situation can be made more complex when the haulage company is an independent third party. Therefore, identifying reasons for loss in quality will clarify where responsibility lies and should help avoid litigation. This research aims to identify the key stress factors that result in loss of crop quality during transit, and what practical techniques growers may be able to adopt either to reduce the incidence of stress, or increase crop tolerance to it.

Summary and main conclusions

- A number of controlled experiments were set up to mimic conditions encountered during the commercial transport of bedding plants. Experiments were carried out in a range of bedding species, with commercially sourced, 6-cell plant trays being used throughout.
- Factors investigated included duration of storage, temperature and humidity regimes, transitions in light and temperature and the use of packaging materials.
- Most of the injuries noted and instances of loss of quality were associated with storage for 48 hours, with a number of crops demonstrating detrimental effects associated with this prolonged period of enclosure.
- Storage in the warmth (22ºC) often resulted in reduced scores compared to cooler storage for the same period.

- Crops that showed adverse effects associated with prolonged warm treatments were Pansy (both winter and spring varieties) Petunia, Cyclamen and Impatiens. In addition to elongated shoots and subsequent loss of uniformity and habit, plants often had a characteristic yellow colouration to the new shoot tips or leaves (Figure 1).

Figure 1. Petunia - Leaf tip yellowing and shoot elongation (etiolation) associated with prolonged storage (particularly at high temperature). Tray 72 = 22^{o}C storage for 48 hours. Tray 41 = glasshouse for equivalent 48 hours.

- The use of cooler temperatures could not guarantee that quality would be retained over the longer storage durations of 48 hours. Cyclamen, Polyanthus and in some cases Petunia exhibited loss of quality after 48 hours at 12^{o}C or 8^{o}C.
- Injury and loss of quality after 24 hours storage was less common, although some species still demonstrated significant reductions in quality.
- Petunia could lose quality after only 24 hours, with effects on both plant habit and flower quality evident. Flowers were particularly susceptible to high humidity (both at 12^{o}C and 22^{o}C).
- There were also some small reductions in quality when plants were held on Danish trolleys for 24 hours, although there was no consistent trend with treatments across species. The poorest treatment for Pansy was 22^{o}C in the open trays; whereas both 12^{o}C with polythene wrapping (poorer growth habit) and 22^{o}C in plants enclosed in boxes (*Botrytis*) marginally reduced quality in Cyclamen.

- Enclosing a flowering crop in boxes or with polythene wrapping also tended to increase ethylene levels compared to leaving the crop open (2 ppm within a polythene wrapped, pansy crop being the highest value recorded).
- Some species such as Dianthus stored well over the shorter 24 hour durations.
- Storage of the crop with wet foliage / flowers could be detrimental, but only with some species. Impatiens showed no effects of leaf wetting but there were slight negative influences on plant habit with Petunia and Polyanthus. Flowers were often more prone to injury than foliage with Petunia, Cyclamen and Pansy all displaying some flower damage when stored wet.
- High humidity could have a negative effect on flower quality (e.g. Petunia – Figure 2). Impatiens, despite being resilient to leaf wetting, also showed increased foliar injury at high humidity compared to low humidity when stored at 22ºC.

Figure 2. Petunia- Effects of high humidity storage for 48 hours. From left to right: Polytunnel control; 22ºC high humidity for 48 hours; 12ºC high humidity for 48 hours.

- Failure to water a crop within 24 hours before storage could result in wilting (especially at higher temperatures) in Impatiens (Figure 3) and Petunia.

Figure 3. Impatiens - Drought stress in plants not watered for 24 hours prior to storage treatments.

- There was no strong evidence to suggest that plants suffered from rapid transitions in temperature, e.g. after being moved from a cooled wagon body directly outside to warm sunny conditions.
- A summary of plant responses is outlined in Table 1. Of the species tested, Petunia and Cyclamen were often the most susceptible to sub-optimal conditions.
- Overall, shorter term storage at lower temperatures (10-12^{o}C) tended to be the optimum treatment for most species (although see specific points above about humidity and packaging).

Table 1. Summary of species susceptibility to the main stress factors imposed. 'X' = reduced quality associated with factor in at least one experiment; 'NT' = treatment not tested and blank spaces = no overall negative effect was found *with the specific conditions & cultivars used in these experiments*.

Factor	Species					
	Cyc.	Dia.	Pan.	Pet.	Pol.	Imp.
Storage for 48 hours at > 20ºC	**X**	**NT**	**X**	**X**		**X**
Storage for 48 hours at < 12ºC	**X**	**NT**		**X**	**X**	
Storage for 24 hours at > 20ºC			**X**	**X**		
Storage for 24 hours at < 12ºC						
High humidity		**NT**		**X**		**X**
Prolonged leaf / flower wetting	**X**	**NT**		**X**	**X**	
Rapid transition in temperature	**NT**	**NT**	**NT**		**NT**	
Rapid transition from dark to light	**NT**	**NT**	**NT**		**NT**	
Polythene wrapped	**X**			**NT**	**NT**	**NT**
Boxed	**X**			**NT**	**NT**	**NT**
Susceptible to *Botrytis*	**X**				**X**	
Susceptible to drought when media dries		**NT**		**X**	**NT**	**X**

Key: Cyc. = Cyclamen, Dia. = Dianthus; Pan. = Pansy; Pet. = Petunia; Pol. = Polyanthus and Imp. = Impatiens

Financial benefits

Differentiating loss in quality due to transportation *per se* and to that of subsequent management issues (e.g. lack of watering at the garden centre) is difficult to determine. Nevertheless, studies in the USA (Armitage, 1993) suggested that up to 20% of floricultural products in the USA could become damaged during transit and retail. Although it is unlikely that such high losses occur in the UK, even a 5% loss of sale of bedding plant material could equate to a retail value of approx. £7 million p.a. (Anon, 2002).

Action points for growers and retailers

- Quality showed a marked deterioration between 24 and 48 hours. Growers (and where appropriate retailers) need to check their transport logistics to ensure crops are delivered as quickly as possible to their FINAL destination.
- Cool chain transport appeared to have some advantages over non-cooled, and again growers may wish to consider adopting this for the longer haul distribution runs.
- Cool storage conditions though, were not without their problems too (high humidity – potential for *Botrytis*, loss of flower quality) and growers cannot be complacent about transport environments just because the wagon fleet has temperature control.
- Watering appeared a key area accounting for variability in crop performance. Crops need to be thoroughly and uniformly watered before transport, but enough time allowed to elapse (1-2 hours ?), to encourage the foliage to dry before loading.
- Visual assessments of watering can be deceptive – trays and plants can look well-watered, but the best way to verify this is feeling the weight of the tray. (e.g. train staff to recognise the underweight trays when packing onto trolleys or into boxes). Such trays may need to be set-aside and re-watered thoroughly before loading.
- Ethylene levels tended to be highest when the cabinets were full of plants, or the crop was enclosed (boxed or polythene wrapped). Ensuring good aeration around a crop could offset injury in ethylene-sensitive cultivars. Growers who have experienced crop rejections may wish to check the packing density of their crops, whether any packaging materials used are required (or provide adequate air flow) and that crops are not leaving the nursery with too much flower present.

Science Section

Introduction

The overall aim of this project is to investigate whether bedding plant crops can suffer significant loss of quality during the transport and distribution stages after production. There have been a number of instances cited where crops have left a nursery in good condition, yet have been rejected by a retailer, due to poor quality. Although the rejection of a crop may be a rare occurrence, it not only results in a loss of income for the producer, but possibly more importantly, a loss of faith in the producer. As such the impact of such events can far outweigh the loss of a single sale. The loss of faith can be a two-way process too, as many producers will genuinely believe they have loaded a 'top quality' crop onto a lorry and will feel aggrieved when it is rejected.

A number of factors will affect crop quality, but this project specifically aims to address those issues associated with the transporting of the crop from production site to retail site. In year 1 of the project we analysed a number of transport distribution 'runs' with the aim of recording the environmental variables crops were likely to encounter (and, if possible, gather any evidence of crop injury in the process). We were particularly interested in questions relating to typical duration of run, highest and lowest temperatures and humidity that crops were exposed to; and whether ethylene was present in the hold of wagons, and if so, at damaging concentrations. Similarly, we aimed to understand more fully the impact of management issues on crop quality, such as watering the crop prior to loading and the associated wetting of the foliage.

The results tended to show that many transport runs followed a similar pattern, with short duration periods and relatively 'benign' temperatures (12-16^{o}C) imposed on the crops. A number of runs (approx 10%), however, highlighted some of the more extreme variables that crops could be exposed to, and which previous literature suggest may be deleterious to plant quality.

The key points from the first year were

- Most transport runs were recorded at temperatures between 11^{o}C and 16^{o}C, although some runs in summer were warmer 18-21^{o}C.
- The previous literature suggested that the warmer temperatures encountered (> 20^{o}C) should be avoided. Loss of quality due to the build up of ethylene and dark respiration are likely to get worse as temperatures rise.
- Relative humidity was often at or near 100%, and occurred both at the higher and lower temperatures.

- Bedding plants were exposed to rapid transitions of temperature and humidity (e.g. from 11ºC to 35ºC in a few minutes, when moved out to direct sunlight).
- During dispatch and transportation, plants are effectively in the dark, for periods of up to 48 hours. Again according to previous literature 36-48 hours in darkness is at about the limit for some bedding plant species.
- The longest duration run recorded was 40 hours with a mean temperature of 16ºC.
- Levels of ethylene recorded in bedding crops in this project were in the range of 1-2.5 ppm. Data from the literature would suggest that these levels are potentially injurious over prolonged exposure periods. We found no direct evidence of ethylene injury, however, when commercial crops were removed from wagons.
- High ethylene levels were recorded in re-distribution centres 'hubs', but these were associated with the presence of a decaying crop (> 20 ppm) or diesel powered machinery (>2.5 ppm).
- Ethylene levels tended to be promoted by the use of enclosed packaging materials, such as shrink-wrapped trolleys or enclosure in cardboard boxes.
- Watering of the crop is an issue for concern – there were examples of crops arriving at their destinations with dry growing media (beginning to wilt) and crops with foliage (and flowers) drenched in water.

In year 2 of the project the aims have been to mimic the conditions recorded in practice in year 1 and to evaluate crop responses to the different environmental factors that the crops may face during a transport run. This was achieved by utilizing controlled environmental cabinets that could control temperature and humidity accurately, and a number of 'walk-in' compartments, that held two Danish trolleys each and were slightly more representative, at least in terms of scale, of a vehicle's storage body.

Materials and Methods

General

Plant material was purchased from commercial nurseries as polystyrene 'double 6-cell-packs'. These were usually delivered mid-week (Tues, Wed or Thurs) and held over the following weekend to acclimatize, before being put through simulated transport experiments the following week (usually initiated on a Mon or Tues). Plants were purchased from nurseries 'early' i.e. at a stage where the crop would normally require 5-10 days on the nursery before being retailed. This enabled the experiments to use material very similar to that which would normally be considered ready for sale (compact growth, first few flowers apparent etc). On arrival, plants were held in a conventional glasshouse, maintained at a temperature range of 18-28ºC depending on time of year (heated winter and well-vented summer). The double 6-cell packs were divided into two trays of 6 plants each. These 6 plant trays were then graded based on overall size, extent of flower development etc. and divided evenly into treatments to minimise any bias associated with the original condition of the plants.

Placement after experimentation varied, but for most experiments plants were placed in a side-netted polytunnel for assessment. This was to mimic the retail environment for bedding plants after transportation (i.e. a garden centre or retail store sales area). The conditions in the assessment area though could vary from one day to the next, and this was taken into account when interpreting data. For example, a control group of plants would be introduced to the tunnel at the same time as those undergoing specific treatments.

Controlled environments

Plants were placed in environmentally controlled cabinets (Saxcil Cabinets Ltd., Cheshire) with temperature ranges of -10 to 40ºC +/- 0.5ºC. The dimensions of these were 100 cm x 120 cm x 150 cm, and plant trays were stacked on bread baskets to mimic conditions experienced with Danish trolleys loaded onto wagons. As such, each cabinet had a capacity of 45 trays. In an attempt to scale up to conditions more realistic of a lorry wagon, however, three 'walk-in' chambers were utilized in some experiments. These were 200 cm x 210 cm x 280 cm and could house two Danish trolleys each (approx x 140 trays in total). Temperature capacity in these was between 10ºC and 35ºC, with air being circulated by fan to ensure even distribution of temperature.

Plant assessment

Packs of bedding were assessed using a modified system developed in PC 200.
Each pack was identified and scored for:
Uniformity within the pack (Poor =1; Moderate =2 and Good = 3)
Plant size (Too Small = 1; Good = 3 and Too Large = 1)
Plant habit (Poor =1; Moderate =2 and Good = 3)
Flower development (Too Little = 1; Good = 3 and Too Much = 1)

Additional assessments on what the observer considered as overall tray quality and plant health (i.e. the extent of physiological damage the plants within the tray possessed; yellow leaves, wilting, any disease symptoms etc.) were based on a wider-ranging score of 1-10. The score of 10 illustrated highest quality, or no injury, respectively.

Trays were assessed at 3 periods: The day previous to any experiment; approximately 3 hours after removal from treatments and after a further 24 hours.

The first reading aimed to provide an initial 'background' score to each tray. The second reading attempted to represent the time bedding would come on sale after delivery to a retail centre. The third was a record to see if plants improved or deteriorated over a further 24 hours. (NB changes were rarely significant between the second and third recordings and only the 3 hour post-treatment data are presented in the report). There was a minimum of 4 people assessing each experiment (more usually 6 were present). Data was handled using an analysis of co-variance, where the first (pre-experiment) scores were used to account for any initial differences between individual trays; i.e. the statistics should take account of any inherent variation between trays that did not relate the experimental procedures. Data are presented with Least Significant Differences (LSD) values. Mean values are significantly different from one another when the difference between the two is greater than the LSD value.

Environmental and plant response measurements

A hand held ethylene meter (ICA Ethylene analyzer – International Controlled Atmosphere Ltd. Kent) was used to measure ethylene levels in cabinets and above crop canopies during the experiments. Levels of ethylene associated with crop injury can be very variable, and depend on factors such as temperature, humidity and the duration of the exposure period.

Species and cultivars also have a very wide range of susceptibility, and it is difficult to predict responses for individual cultivars without a number of detailed tests. Nevertheless, a fairly good point of reference for this study is the work of Dostal *et al.*, (1991) on New Guinea Impatiens, which demonstrated that as little as 4 hours exposure to 1 ppm ethylene could be damaging.

Chlorophyll fluorescence was also used on a number of occasions to determine if the environmental conditions had induced any stress to the foliage of plants. Chlorophyll fluorescence values of variable fluorescence divided by the maximum fluorescence (Fv/Fm) should give a value greater than 0.7 if plant leaves are healthy. Values below this tend to indicate physiological stress.

Experimental Materials, Methods and Results

Experiment 1. Temperature and duration of transport conditions using Autumn and Spring bedding

Year 1 data illustrated that some nurseries used chilling units in wagons while others did not. Temperature profiles in chilled lorries suggested temperatures were often 10-12ºC, whereas one of the highest prolonged temperatures recorded in a non-chilled wagon was 20-22ºC. The objective of Exp 1 was to determine what the effects of these temperatures would be on crop quality, when plants were exposed to them in darkness for either 24 or 48 hour periods. It was also observed in year 1 that crops were often transported with the leaves wet and wagon humidity high. To mimic the leaf wetting half the samples in this experiment were watered immediately before placement into cabinets. They were also sprayed twice a day with a hand mister to ensure the foliage remained wet for the entire period in the cabinet (spraying was done quickly to minimise the disturbance to the cabinet environment).

Full treatment combinations were:

Con 24h: Control plants moved from holding glasshouse to polytunnel after 24 hours.
Con 48h: Control plants moved from holding glasshouse to polytunnel after 48 hours.
12C 24h: Plants kept at 12ºC for 24 hours
12C 48h: Plants kept at 12ºC for 48 hours
22C 24h: Plants kept at 22ºC for 24 hours
22C 48h: Plants kept at 22ºC for 48 hours
Wet 12C 24h: Plants kept at 12ºC for 24 hours, with foliage kept wet throughout

Wet 12C 48h: Plants kept at 12°C for 48 hours, with foliage kept wet throughout
Wet 22C 24h: Plants kept at 22°C for 24 hours, with foliage kept wet throughout
Wet 22C 48h: Plants kept at 22°C for 48 hours, with foliage kept wet throughout

Autumn Bedding

Three species were selected as typical of autumn bedding plants –
Winter Pansy (Pansy F1 Mixed)
Cyclamen (Mini Cyclamen Mixed)
Polyanthus (Polyanthus F1 Mixed)

Experiments were carried out between 2nd and 6th October 2006 and each treatment was represented by 12 trays per species.

Spring Bedding

Species selected were

Spring Pansy (F1 Mixed)
Petunia (Petunia F1 Mixed)
Impatiens (Impatiens F1 Mixed).

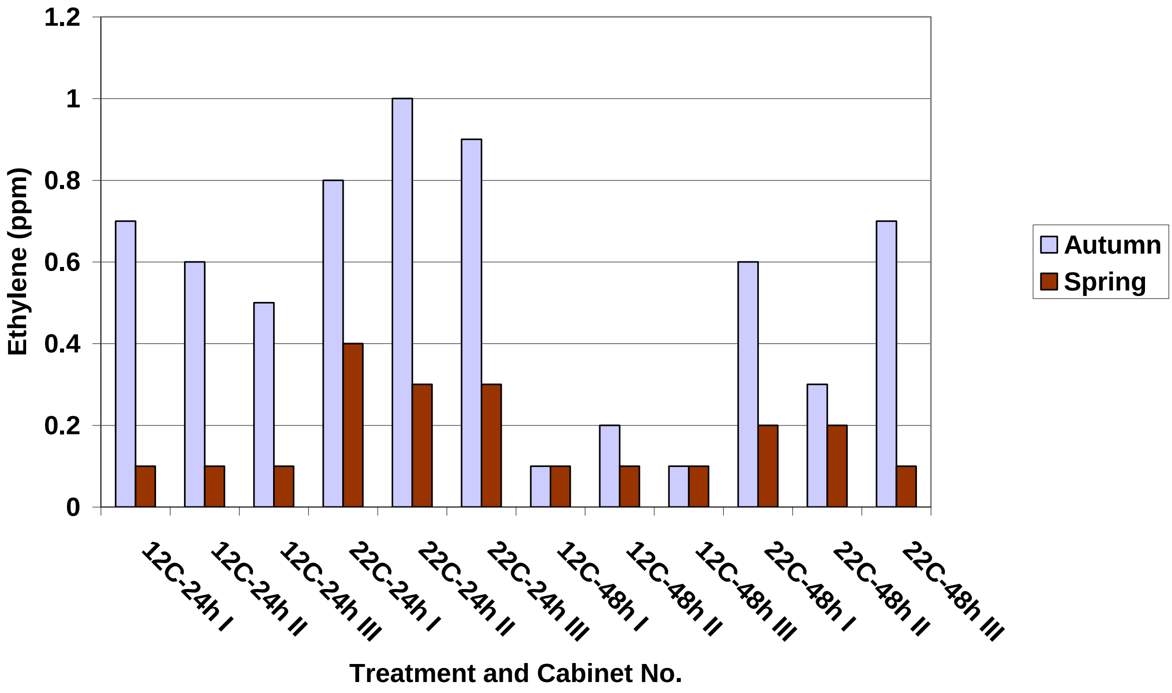
Experiments were carried out between 23rd and 26th April 2007. There were 12 replicate trays per species per treatment.

Results

Ethylene readings were highest during the autumn experiments, but the peak recording was only 1 ppm (Figure 4). There was generally more crop in flower in the autumn and this may have contributed to higher seasonal readings. However, as the cabinets were holding mixed crops, differences may also relate to a particular species, e.g. the Polyanthus or the Cyclamen that were present in the autumn but not the spring. Of interest was the fact that ethylene levels were highest after 24 hours and had reduced by 48 hours, however, this also corresponded with half of each crop being removed after 24 hours, so there was a lower plant density associated with the later readings.

Figure 4. Ethylene levels (ppm) recorded in cabinets (3 per treatment) during temperature and duration experiments in Autumn 2006 and Spring 2007.

NB previous research has shown that as little as 4 hours exposure to 1 ppm ethylene can be damaging to some crops.



Winter Pansy

Overall quality was significantly lower with plants kept at 22^{o}C for 48 hours (Figure 5), and for the plants not wetted this was reflected in a reduced health score (Figure 6). Injury tended to be associated with leaf yellowing, and on some occasions, downy mildew (*Peronospora violae)* infection. Other quality parameters (Table 1) were not necessarily lowest in these treatments; although the non-wetted 22C 48h treatment scored poorly on plant habit. There appeared to be no overall disadvantage associated with keeping the foliage (or flowers) wet in any environment. Flower development scores were generally low across treatments because of relatively few flowers on the crop (2-3 per tray) at the time of treatment.

Figure 5. Winter Pansy – Quality score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.

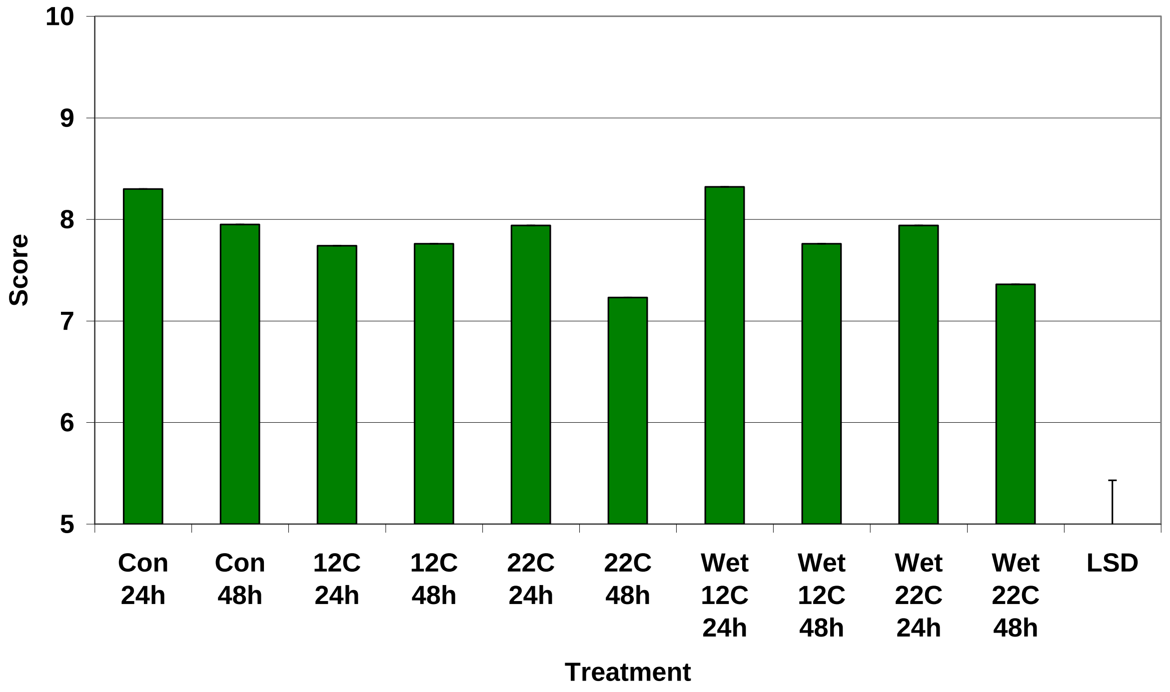


Figure 6. Winter Pansy – Plant health score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.

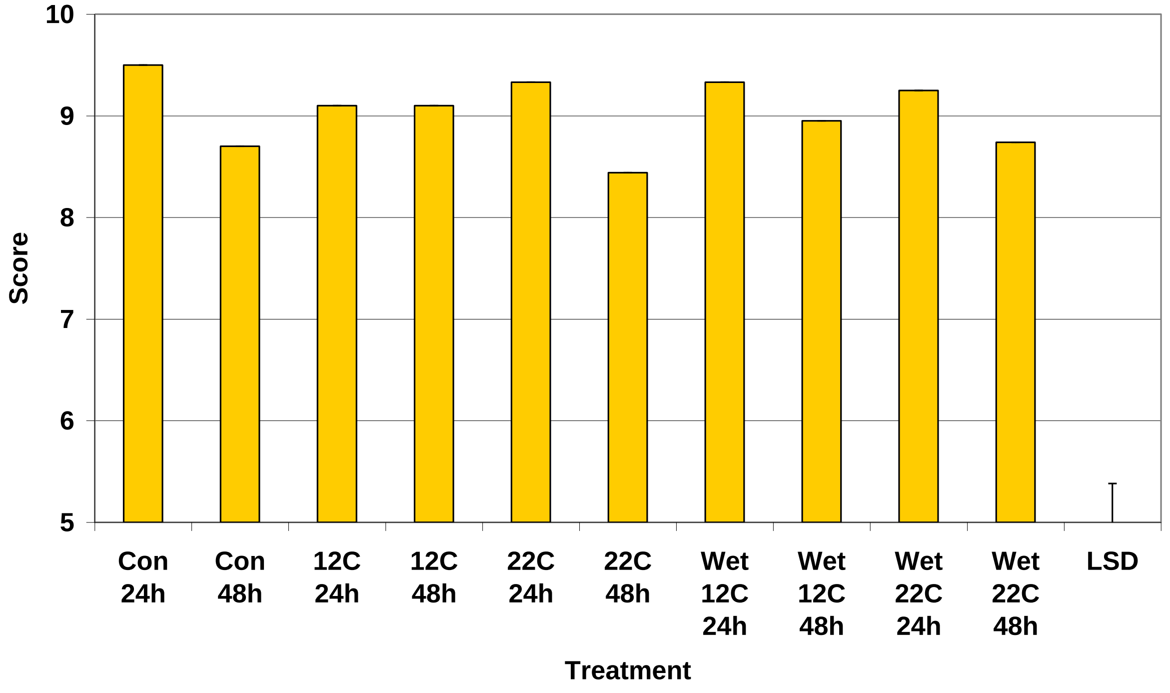


Table 1. Winter Pansy – Mean scores for crop uniformity, size, habit and flower development after storage at different temperatures and durations, and with some plants retaining wet foliage throughout.

		Con	12 C		22 C	
				Wet		Wet
Uniformity	24h	2.42	2.12	2.55	2.35	2.34
	48h	2.68	2.41	2.31	2.40	2.63
					LSD = 0.289	
Size	24h	2.49	2.84	2.53	2.32	2.49
	48h	2.50	2.62	2.37	2.63	2.25
					LSD = 0.402	
Habit	24h	2.57	2.42	2.73	2.40	2.46
	48h	2.44	2.40	2.15	2.25	2.36
					LSD = 0.286	
Flower	24h	1.50	1.25	1.42	1.29	1.00
	48h	1.22	1.39	2.13	1.50	1.07
					LSD = 0.365	

Cyclamen

These plants appeared relatively consistent in their performance (Table 2), with only a slight loss of quality associated with Wet 12C 48h (Figure 7). However, health scores were generally less when plants had been stored for 48 hours rather than 24 hours (Figure 8). Reductions in health and overall quality scores were often associated with infection by *Botrytis cinerea* (both on flowers and on leaves near the crown of the plant). Longer storage periods appeared to accentuate the problem. Flower quality could also be lower (e.g. extended petioles and senescent petals) in the 12°C Wet 48 hour treatment without any direct evidence of *Botrytis*.

Figure 7. Cyclamen – Quality score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.

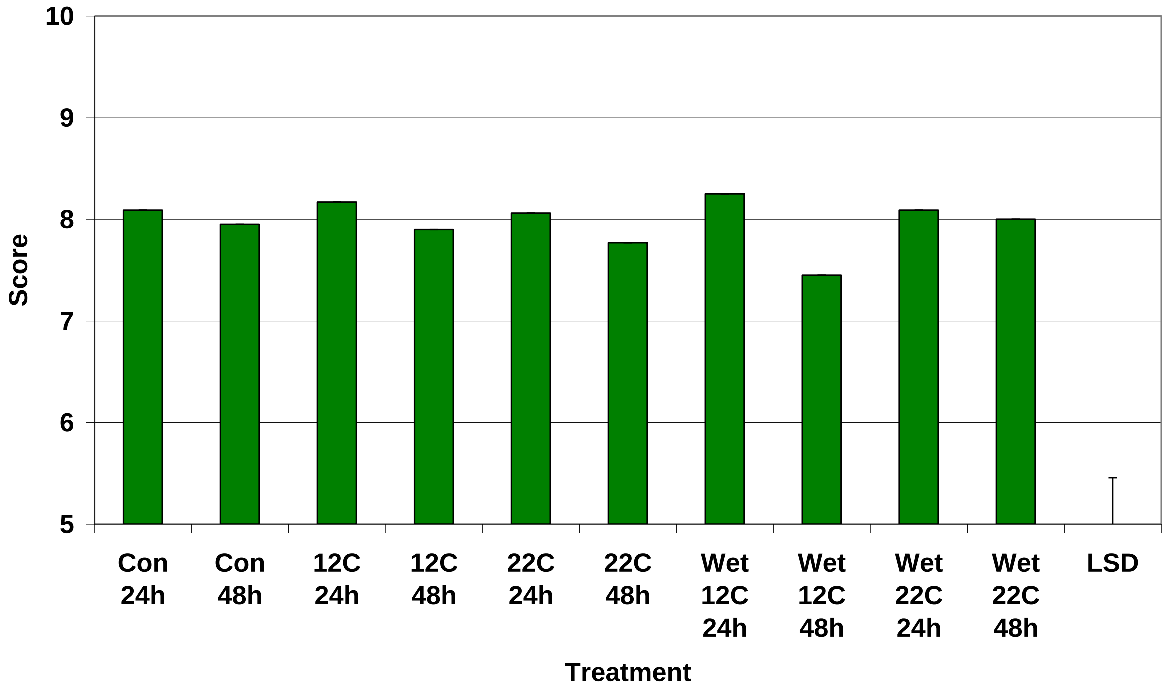


Figure 8. Cyclamen – Plant health score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.

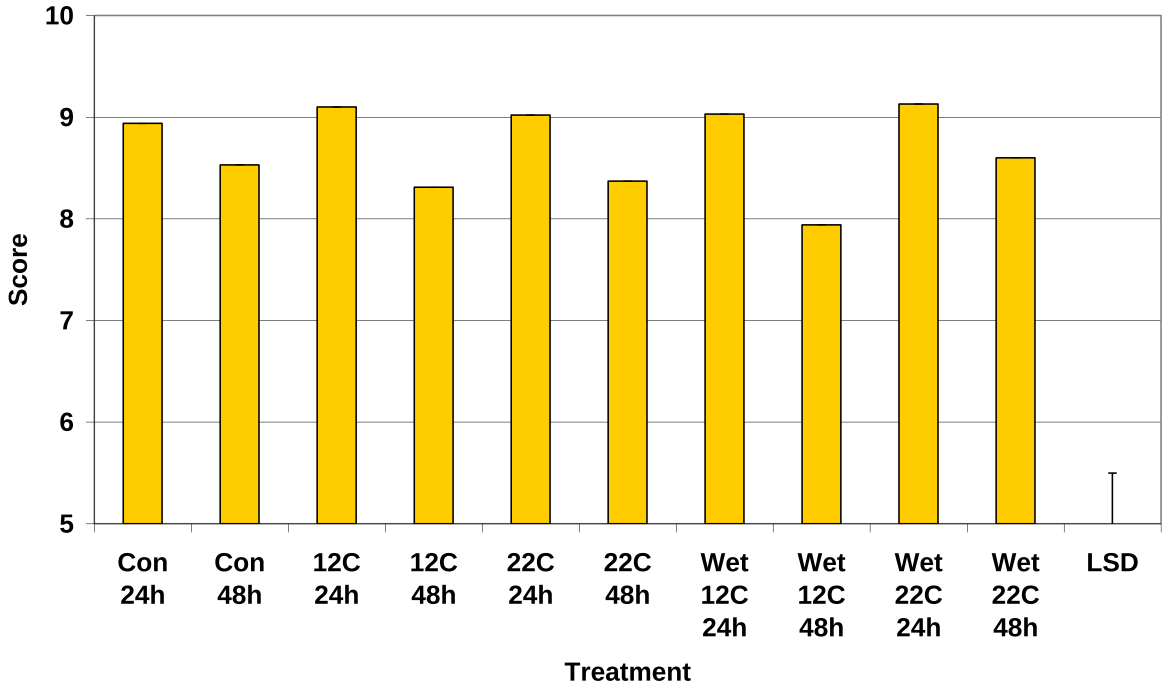


Table 2. Cyclamen – Mean scores for crop uniformity, size, habit and flower development after storage at different temperatures and durations, and with some plants retaining wet foliage throughout.

Cyclamen		Con	12 C		22 C	
				Wet		Wet
Uniformity	24h	2.37	2.49	2.46	2.23	2.54
	48h	2.28	2.39	2.24	2.60	2.46
					LSD = 0.289	
Size	24h	2.74	2.71	2.69	2.61	2.44
	48h	2.72	2.52	2.53	2.86	2.92
					LSD = 0.345	
Habit	24h	2.66	2.70	2.69	2.57	2.72
	48h	2.64	2.56	2.57	2.69	2.77
					LSD = 0.230	
Flower	24h	2.27	2.44	2.67	2.46	2.32
	48h	2.76	2.49	2.04	2.61	2.50
					LSD = 0.403	

Polyanthus

Polyanthus showed some loss of quality after exposure to 12^{o}C for 48 hours, although values were also quite low for the Con 48h (Figures 9 and 10). Each treatment had some sub-standard trays, but generally aspects such as leaf yellowing or wilting, and *Botrytis* infection of the flowers was most prevalent in the longer duration 12^{o}C treatments. Older leaves under the canopy being particularly prone to yellowing. Loss of quality in other treatments could also be related to size and habit (Table 3). For example, exposure at 22^{o}C for 48 hours tended to result in over-large specimens and as a consequence reduced size scores (Table 3).

Figure 9. Polyanthus – Quality score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.

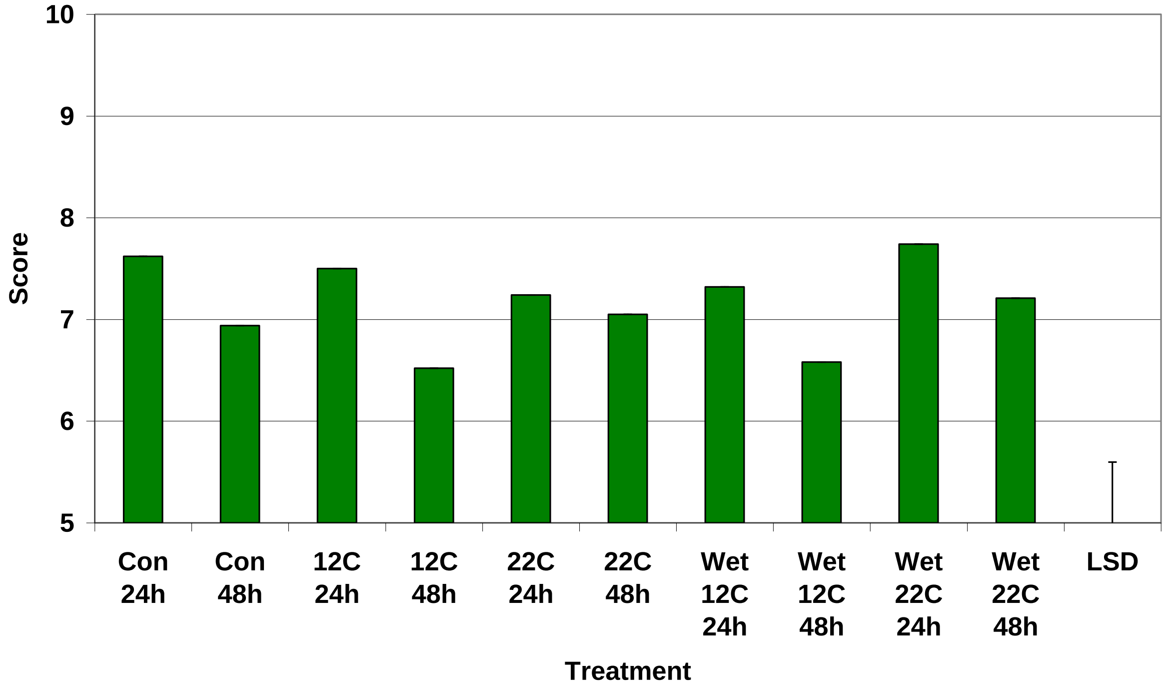


Figure 10. Polyanthus – Plant health score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.

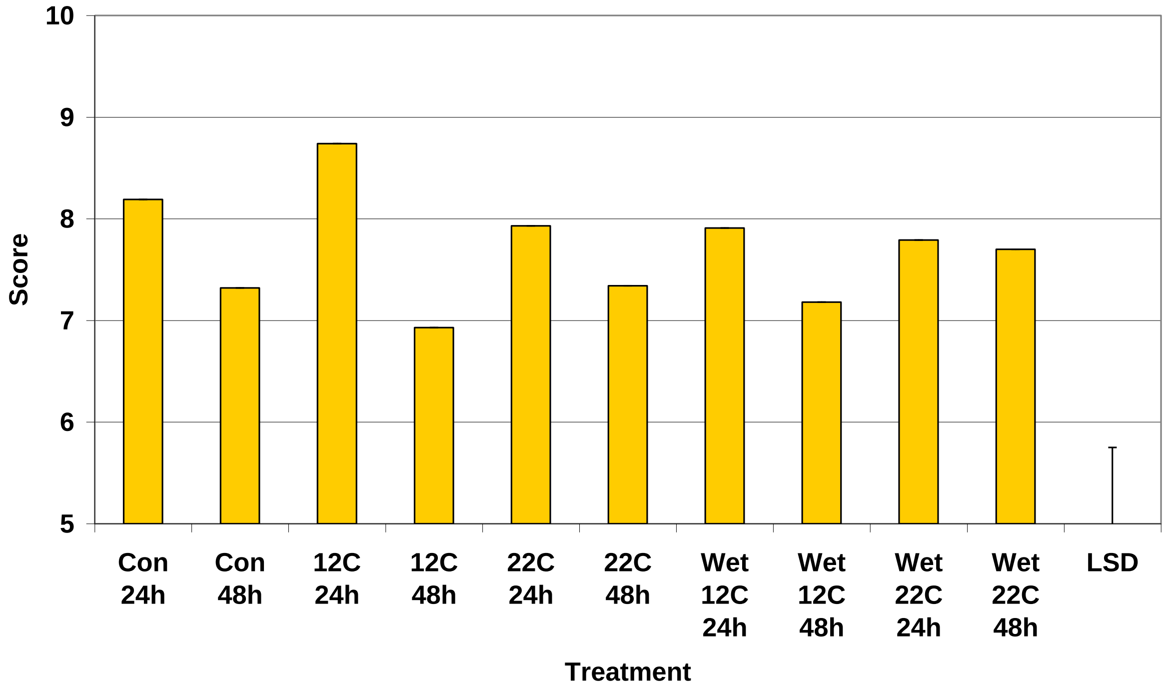


Table 3. Polyanthus – Mean scores for crop uniformity, size, habit and flower development after storage at different temperatures and durations, and with some plants retaining wet foliage throughout.

Polyanthus		Con	12 C		22 C	
				Wet		Wet
Uniformity	24h	2.38	2.24	2.31	2.27	2.52
	48h	2.25	1.99	2.10	2.36	2.07
					LSD = 0.310	
Size	24h	2.75	2.26	2.69	2.60	2.63
	48h	2.24	2.51	2.33	1.89	1.26
					LSD = 0.403	
Habit	24h	2.49	2.43	2.47	2.30	2.67
	48h	2.31	2.18	2.05	2.26	2.09
					LSD = 0.274	
Flower	24h	2.11	1.49	1.74	1.56	2.12
	48h	1.80	1.68	1.90	2.40	2.69
					LSD = 0.435	

Spring bedding

Pansy

Quality was reduced by the 22^{o}C for 48 hour treatment, particularly when the foliage was wetted (Figure 11). There were some physiological problems of leaf yellowing (Figure 12), but a large part of loss of quality was associated with the stretching of the crop under the dark warm conditions (see significantly reduced habit scores in Table 4).

Petunia

Loss of crop quality was possibly most dramatic in Petunia. Again plants exposed to 22^{o}C for 48 hours showed elongation and the development of yellow shoot tips (etiolation) (Figures 13 and 14). Also of note was the reduction in plant quality (size and habit) after storing plants wet at 22^{o}C for only 24 hours (Figure 13 and Table 5).

Figure 11. Spring Pansy – Quality score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.

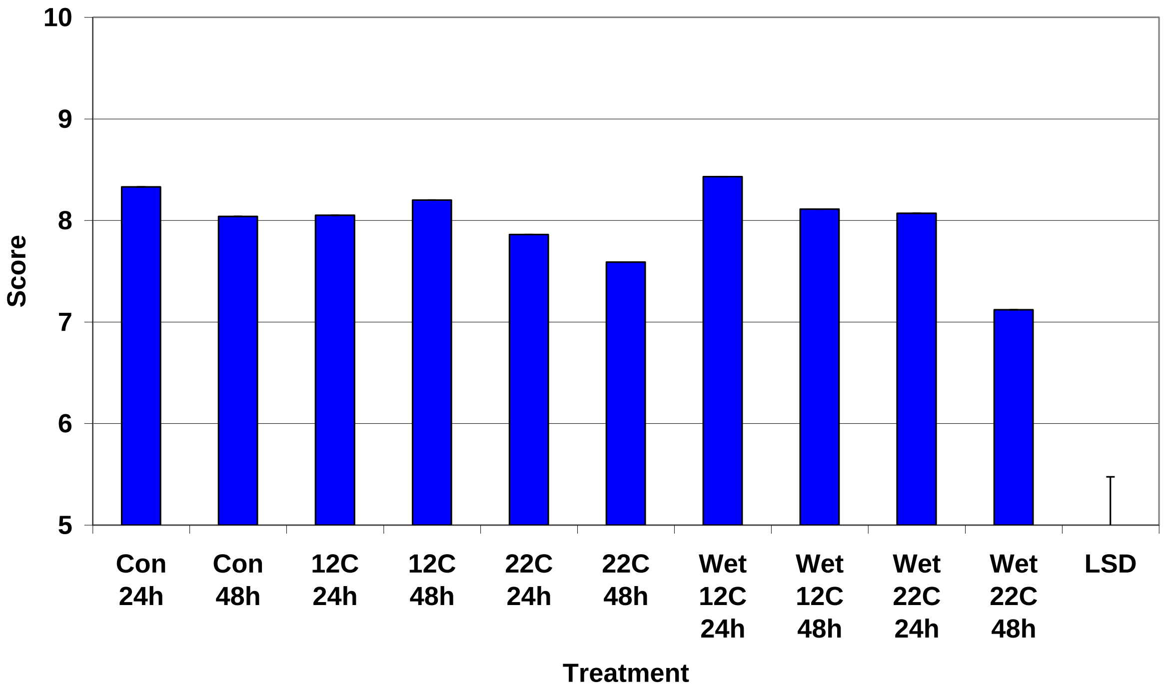


Figure 12. Spring Pansy – Plant health score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.

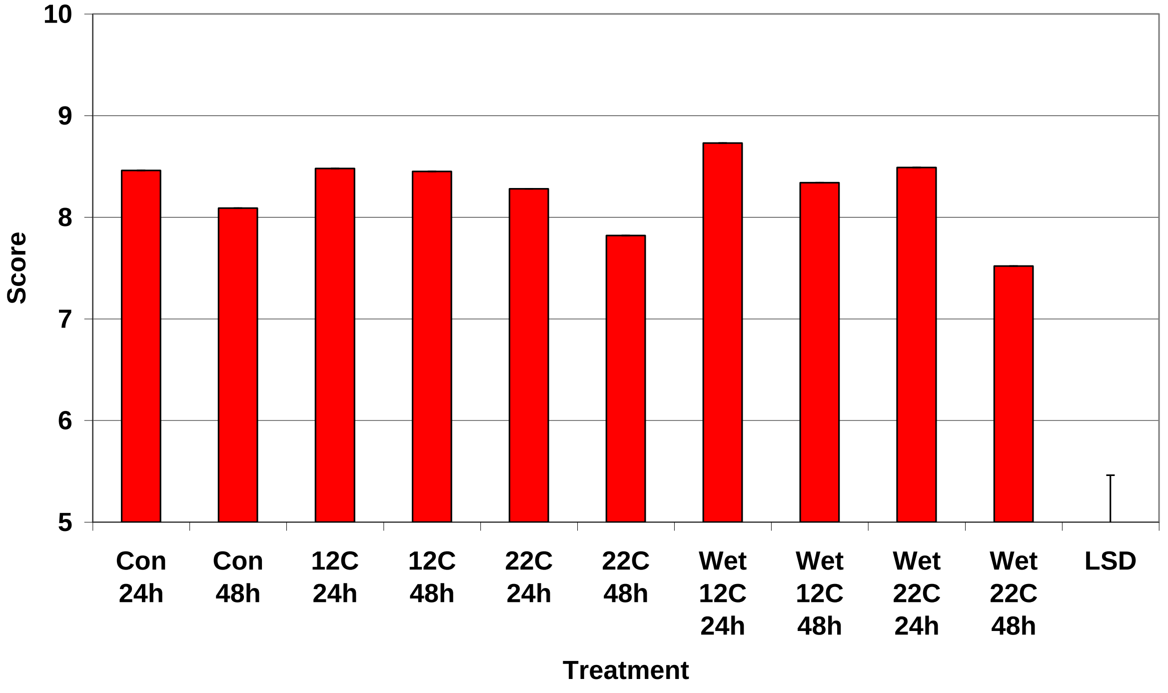


Table 4. Spring Pansy – Mean scores for crop uniformity, size, habit and flower development after storage at different temperatures and durations, and with some plants retaining wet foliage throughout.

		Con	12 C		22 C	
				Wet		Wet
Uniformity	24h	2.38	2.36	2.25	2.30	2.31
	48h	2.38	2.37	2.22	2.18	2.27
					LSD = 0.302	
Size	24h	2.21	2.14	2.38	1.89	2.53
	48h	2.04	2.26	2.34	1.87	1.67
					LSD = 0.378	
Habit	24h	2.47	2.25	2.21	2.24	2.24
	48h	2.37	2.39	2.12	1.88	1.86
					LSD = 0.268	
Flower	24h	2.31	2.54	2.45	2.28	2.50
	48h	2.05	2.63	2.41	2.15	2.11
					LSD = 0.335	

Figure 13. Petunia – Quality score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.

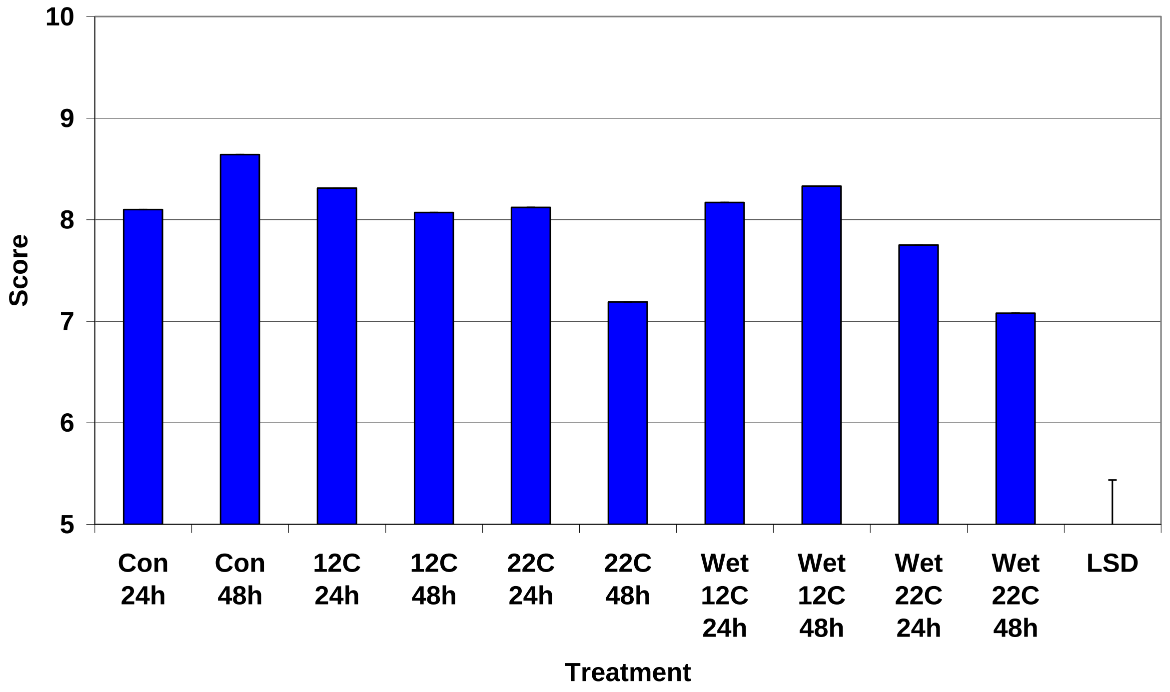


Figure 14. Petunia – Plant health score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.

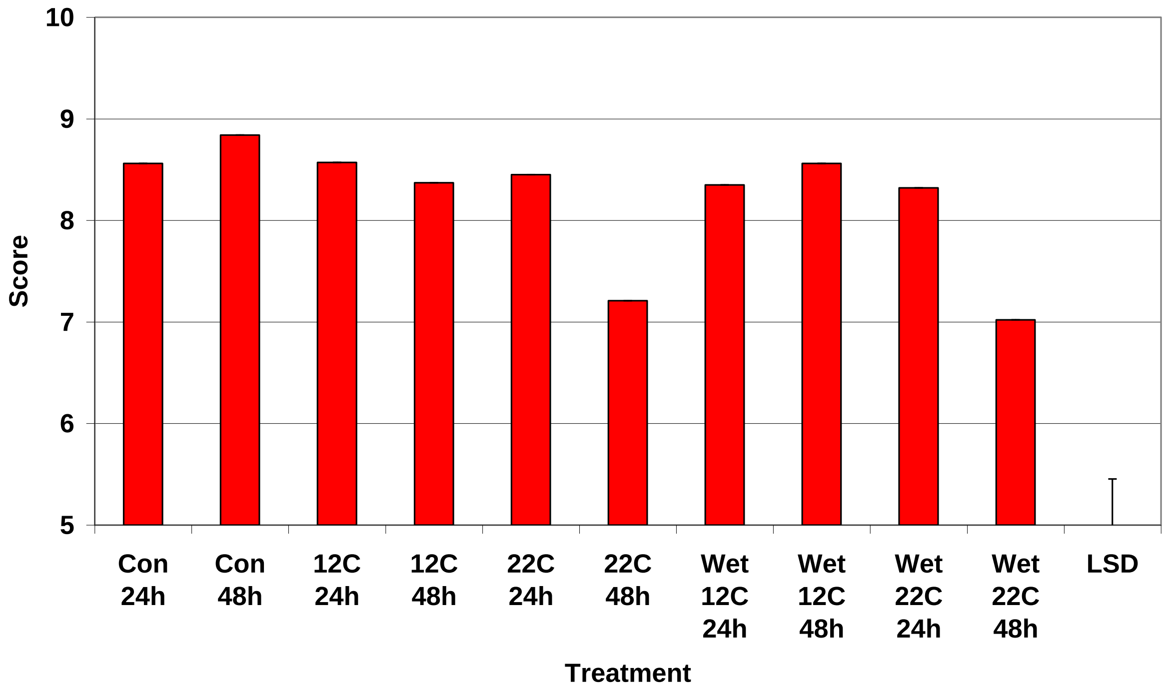


Table 5. Petunia – Mean scores for crop uniformity, size, habit and flower development after storage at different temperatures and durations, and with some plants retaining wet foliage throughout.

		Con	12 C		22 C	
				Wet		Wet
Uniformity	24h	2.99	2.34	2.18	2.05	2.03
	48h	2.26	1.86	2.17	2.21	2.38
					LSD = 0.275	
Size	24h	2.40	2.45	2.47	2.13	1.85
	48h	2.35	2.47	2.33	1.82	1.52
					LSD = 0.419	
Habit	24h	2.19	2.51	2.29	2.22	1.94
	48h	2.42	2.26	2.27	1.61	1.60
					LSD = 0.241	
Flower	24h	1.46	1.24	1.31	1.24	1.16
	48h	1.24	1.89	1.20	1.35	1.35
					LSD = 0.327	

Impatiens

This species appeared relatively resilient to the treatments imposed (Figures 15 and 16). There was a marginal loss of quality associated with 22ºC, especially growth extension resulting in some large plants and loss of uniformity after 48 hours (Table 6), but otherwise no physiological injury was noted.

Figure 15. Impatiens – Quality score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.

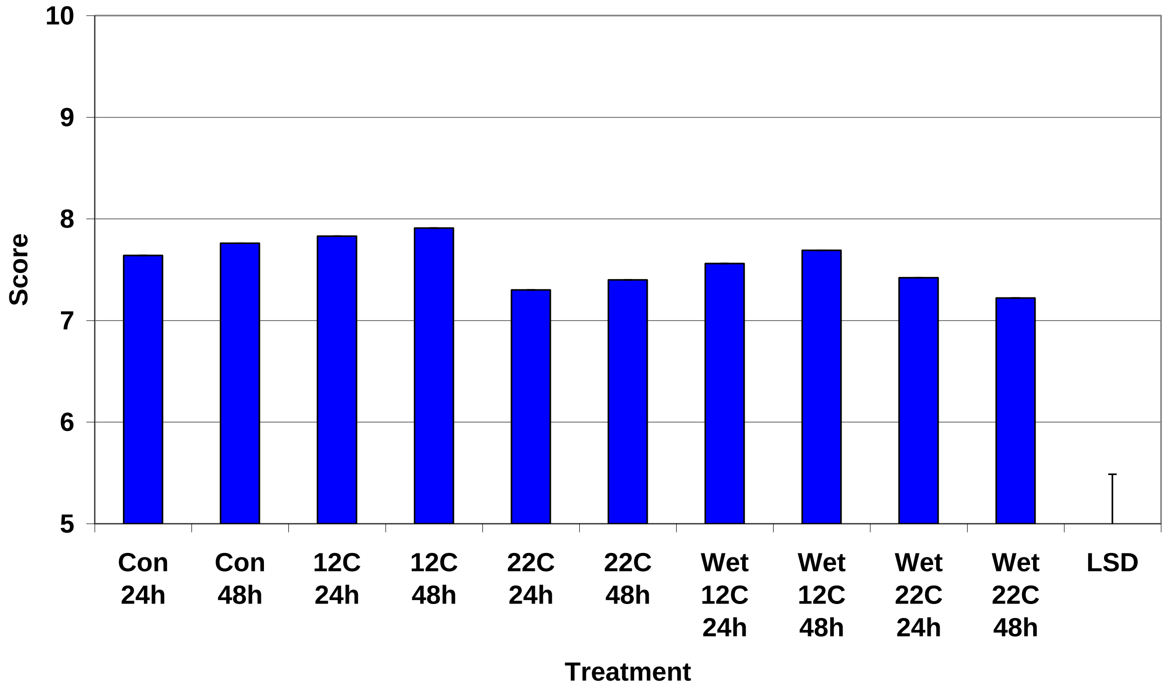


Figure 16. Impatiens – Plant health score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.

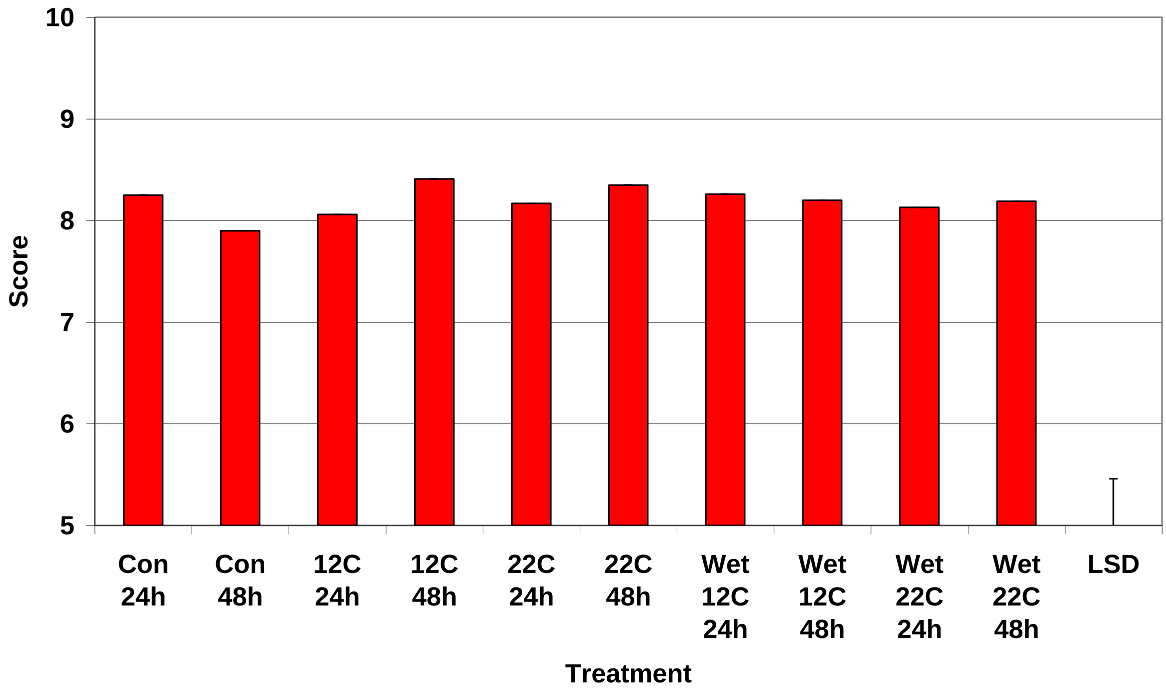


Table 6. Impatiens – Mean scores for crop uniformity, size, habit and flower development after storage at different temperatures and durations, and with some plants retaining wet foliage throughout.

Impatiens		Con	12 C		22 C	
				Wet		Wet
Uniformity	24h	2.25	2.30	2.05	1.89	2.18
	48h	2.26	2.23	2.16	2.04	1.90
					LSD = 0.300	
Size	24h	2.31	2.48	2.65	2.29	2.31
	48h	2.14	2.47	1.94	1.63	1.44
					LSD = 0.389	
Habit	24h	2.06	2.21	2.17	2.23	2.17
	48h	2.43	2.57	2.54	2.27	2.24
					LSD = 0.277	
Flower	24h	2.66	2.13	2.22	2.28	2.34
	48h	2.46	2.58	2.72	2.61	2.65
					LSD = 0.376	

Experiment 2. The rapid transition of bedding plants from wagons to high light and temperature conditions outdoors

The aim of this experiment was to determine if bedding plants could suffer injury or loss of quality when moved rapidly from the controlled temperatures and darkness associated with lorry wagons to bright light and high temperature conditions. The experiment was designed to mimic the scenario of a wagon unloading at a garden centre on a warm, sunny summer day. We were also interested to determine whether previous management affected plant responses and some plants were maintained with wet leaves during the storage period (as has been found in practice the previous year), and another group were not watered for 24 hours previous to being placed in storage (to mimic the occasional tray that may be have been missed in the watering before transportation). A control group of plants at each temperature were watered 2 hours before treatments commenced, and any excess water carefully shaken off the foliage. Plants were maintained in the dark within controlled temperature cabinets for 24 hours before being placed outdoors on 8 July (temperature 29^{o}C and 1,250 μmol s^{-1} m^{-2} {65,000 lux}). Plants were assessed for chlorophyll fluorescence parameters approximately 30 minutes after placement outdoors and for visual quality assessments after 2 hours.

Full storage treatments were;

Polytunnel throughout (Poly Con)
Polytunnel throughout but not watered for 24 hours beforehand (Poly Dry)
Polytunnel throughout but leaves sprayed with water 3 times a day (Poly WetL)
35^{o}C in the dark (35C Con)
35^{o}C in the dark but not watered for 24 hours beforehand (35C Dry)
35^{o}C in the dark but leaves sprayed with water 3 times a day (35C WetL)
12^{o}C in the dark (12C Con)
12^{o}C in the dark but not watered for 24 hours beforehand (12C Dry)
12^{o}C in the dark but leaves spayed with water 3 times a day (12C WetL)
8^{o}C in the dark (8C Con)
8^{o}C in the dark but not watered for 24 hours beforehand (8C Dry)
8^{o}C in the dark but leaves sprayed with water 3 times a day (8C WetL)

Impatiens F1 White and Petunia F1 Red were used. There were 12 trays per treatment per species.

Results

Chlorophyll fluorescence values Fv/Fm

Chlorophyll fluorescence values tended to be lowest in the 35ºC treatment when plants were kept dry, although mean values were always greater or equal to 0.7. (i.e. any injury induced may be short-term). Although this treatment gave the lowest values in Petunia, the values were not significantly different from most other treatments (Figure 17). In contrast, although the absolute values were higher in Impatiens, they were significantly lower in this dry treatment compared to the 35ºC control (Figure 18). There was no evidence of photosynthetic disruption in Petunia when plants were moved outdoors after storage in cool environments. The results from Impatiens are slightly more puzzling as there are some lower Fv/Fm scores with 12ºC and 8ºC, but only with the non-treated (Con) plants, not those either kept dry or with the foliage kept wet.

Petunia

Quality scores were quite variable for the Petunia (Table 7 and Figure 19), but this was more to do with variations between trays, rather than any strong treatment effect. Despite the use of grading and the covariate analysis, some trays were deemed poor quality irrespective of imposed treatments. For example the relatively low quality score in the 12ºC controls (Figure 19) was possibly due to poor shape in plants from a couple of the trays bringing the mean value down. There was no corresponding loss of health with this treatment (Figure 20) despite notes suggesting some yellowing of leaf tips in a few plants. Again, the fact that trays were variable in quality before treatment may have masked some of these health factors. However, when one factor associated with reduced quality, (such a yellowing of the shoot tips) is isolated in the analysis, there still appears to be a strong correlation between higher treatment temperature and loss of quality (Figure 21).This illustrates the issue of how different people define quality and health, and that the factors they base quality on, may vary between different individuals, i.e. compare data for the 12ºC treatment between Figures 20 and 21.

Figure 17. Petunia – Chlorophyll fluorescence values (Fv/Fm) after storage at different temperatures with plants either watered 2 hours (Con) or 24 hours (Dry) before treatment, or retaining wet foliage throughout (WetL).

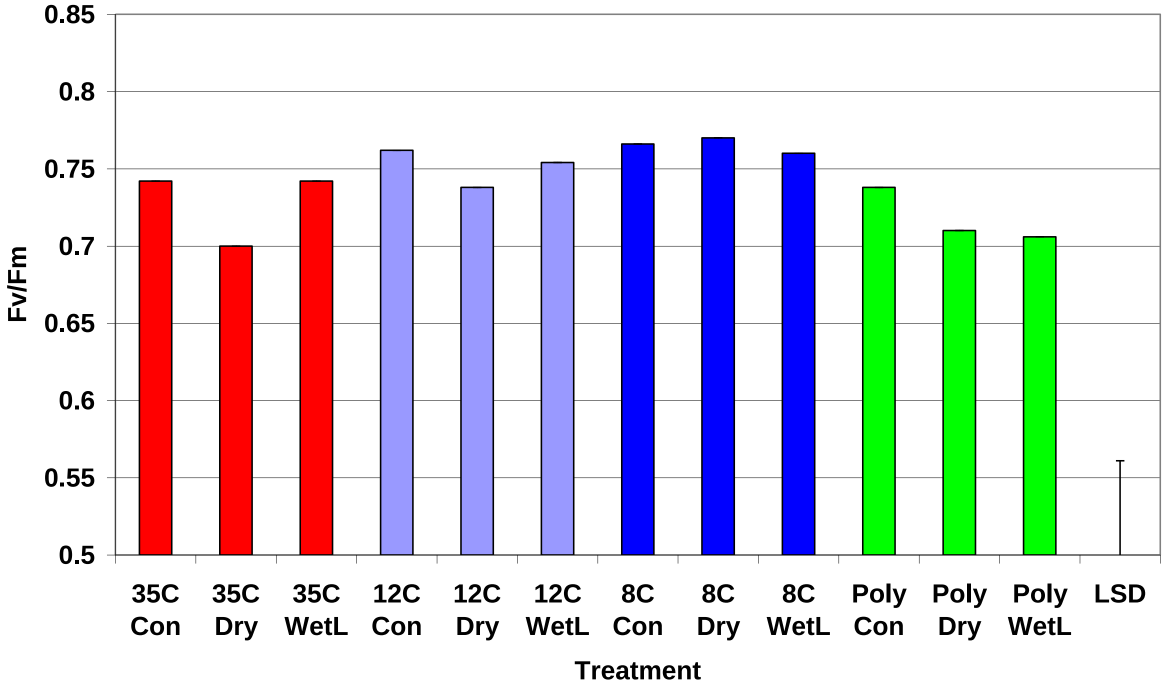
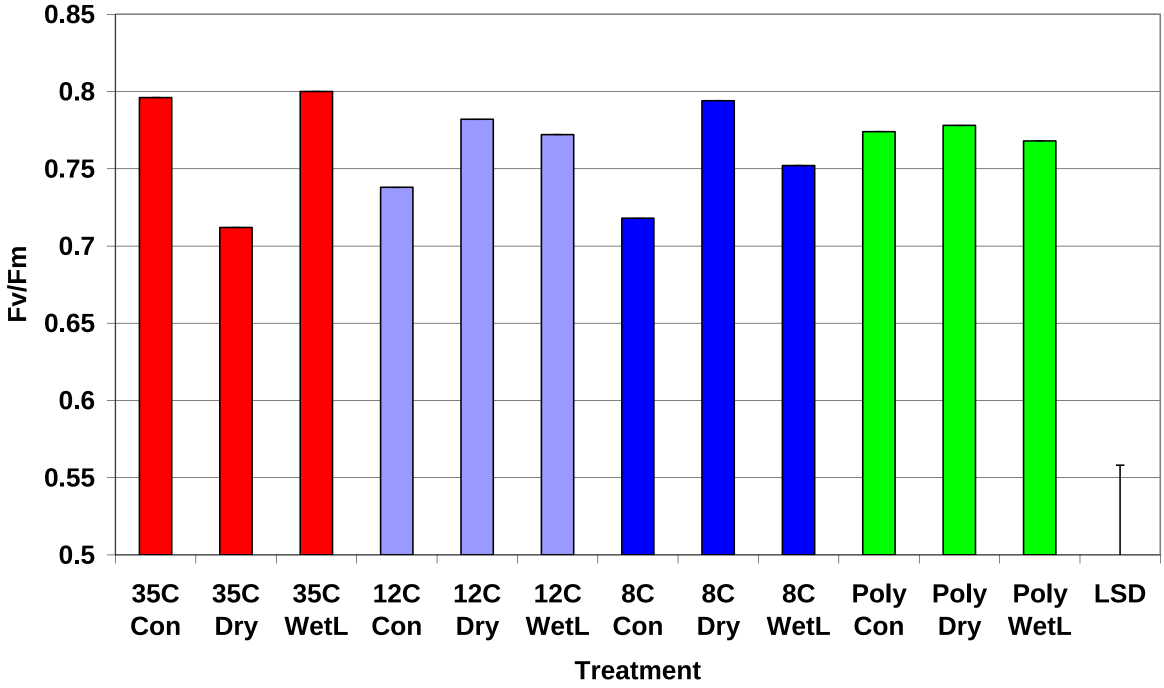


Figure 18. Impatiens – Chlorophyll fluorescence values (Fv/Fm) after storage at different temperatures with plants either watered 2 hours (Con) or 24 hours (Dry) before treatment, or retaining wet foliage throughout (WetL).



There was some physiological injury noted in the 35ºC dry treatment, but not enough to have an influence on the overall quality score. Similarly, loss of quality in the 8ºC plants may have been induced when the leaves were kept wet, but again this was not reflected in the health scores.

Table 7. Petunia – Mean scores for crop uniformity, size, habit and flower development after storage at different temperatures with plants either watered 2 hours (Con) or 24 hours (Dry) before treatment, or retaining wet foliage throughout (Wet Leaves).

		Con	Dry	Wet Leaves
Uniformity	35ºC	1.95	1.93	2.00
	12ºC	2.13	2.39	2.33
	8ºC	2.06	2.52	2.38
	Poly	2.36	1.82	2.21
	LSD			0.407
Size	35ºC	1.08	2.06	1.98
	12ºC	1.58	2.02	2.08
	8ºC	1.80	1.63	2.11
	Poly	2.00	2.20	2.21
	LSD			0.635
Habit	35ºC	1.68	2.12	2.07
	12ºC	1.88	2.15	2.21
	8ºC	2.12	2.17	1.99
	Poly	2.07	2.16	2.19
	LSD			0.427
Flower	35ºC	1.89	2.15	1.95
	12ºC	2.02	2.08	1.75
	8ºC	1.81	2.35	1.89
	Poly	1.62	2.02	1.68
	LSD			0.610

Figure 19. Petunia – Quality score after storage at different temperatures with plants either watered 2 hours (Con) or 24 hours (Dry) before treatment, or retaining wet foliage throughout (WetL).

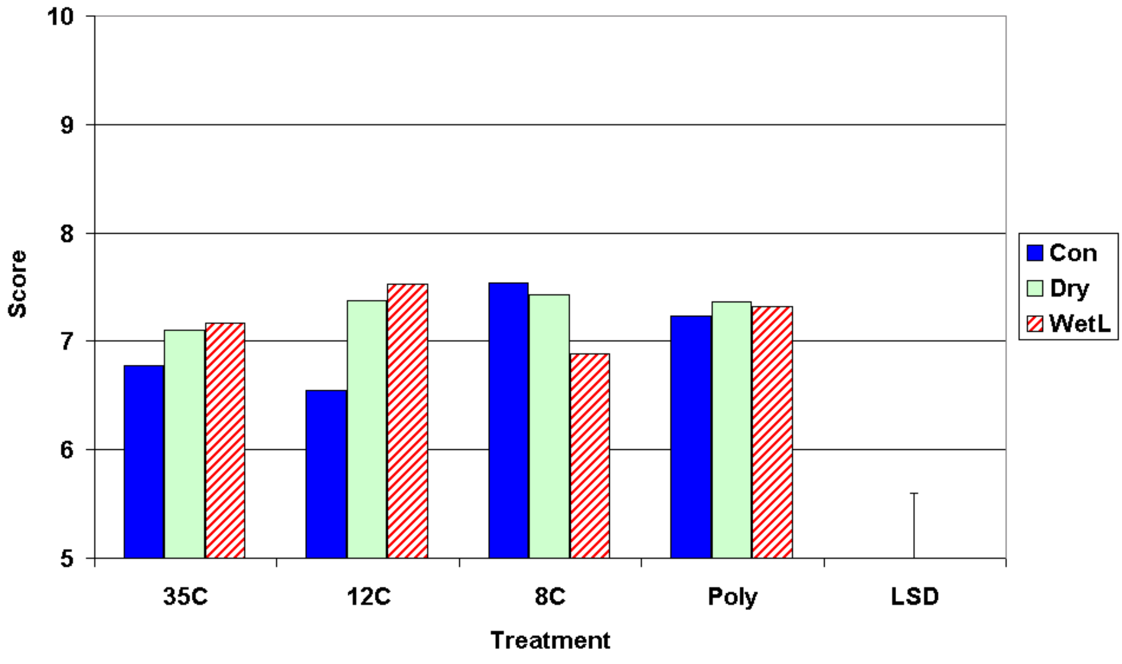


Figure 20. Petunia – Plant health score after storage at different temperatures with plants either watered 2 hours (Con) or 24 hours (Dry) before treatment, or retaining wet foliage throughout (WetL).

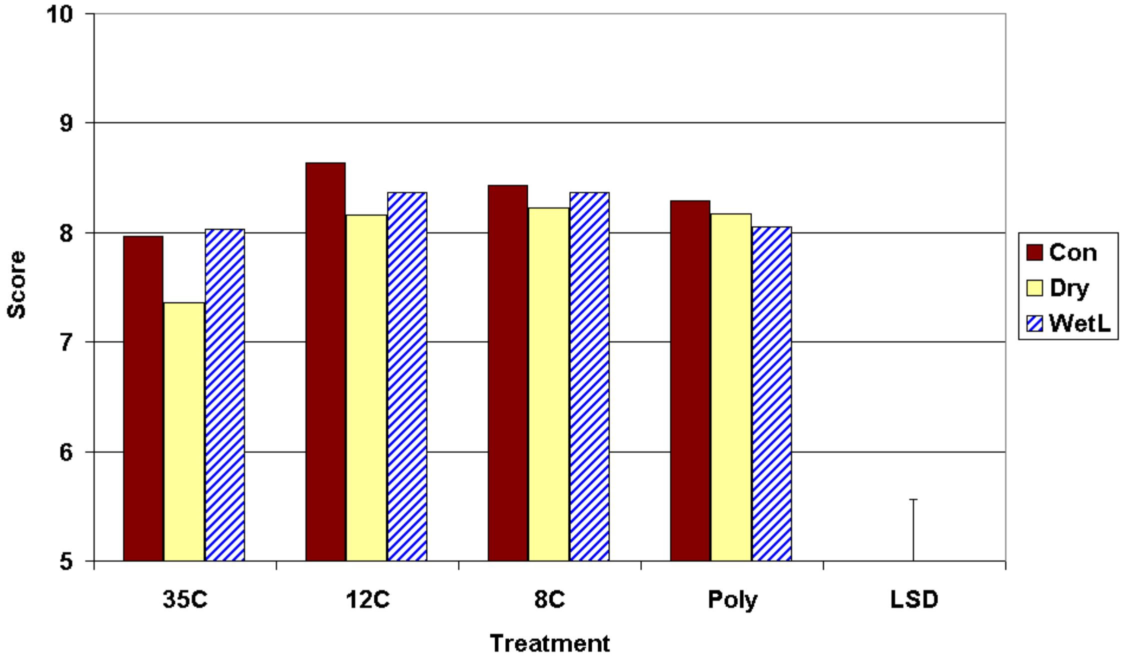
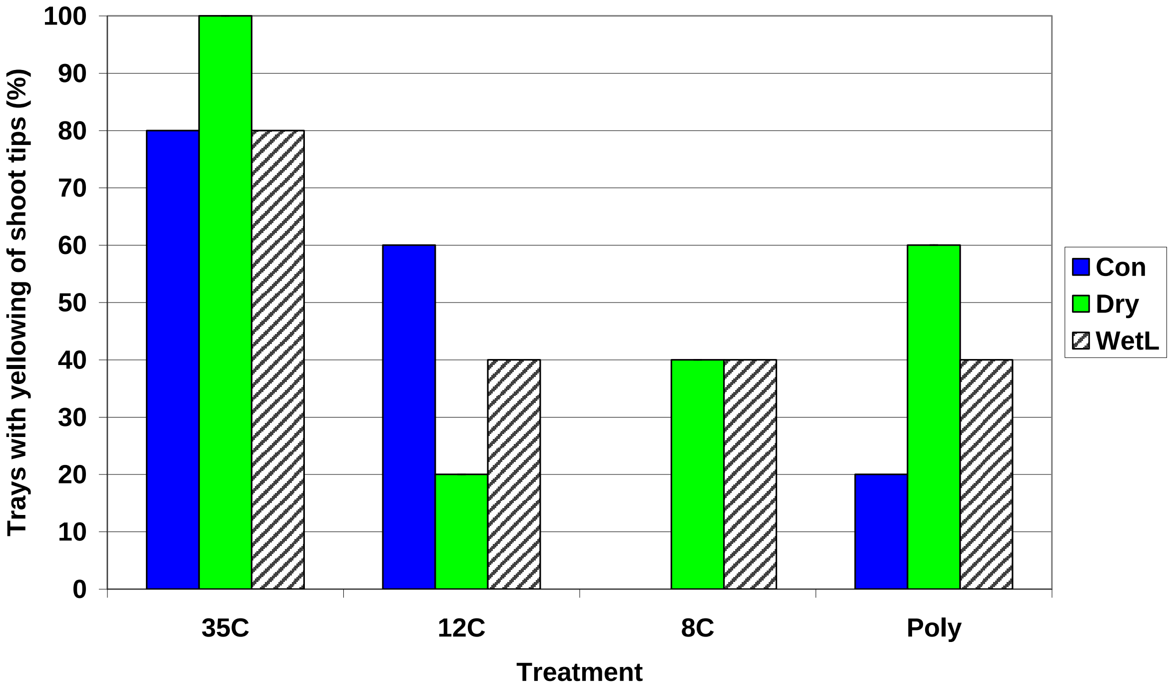


Figure 21. Petunia – Percentage of trays in different treatments where one or more plant exhibited yellowing of the shoot tips. Trays were stored at different temperatures with

plants either watered 2 hours (Con) or 24 hours (Dry) before treatment, or retaining wet foliage throughout (WetL).



Impatiens

Impatiens was susceptible to wilting and loss of quality in the dry treatment at 35ºC (Figures 22 and 23 and also scores for uniformity, habit and flower development – Table 8). To a lesser extent there was also some reduction in health scores in Polytunnel plants under the dry treatment too – Figure 23. Storing plants with wet leaves had no detrimental effect in any environment. Also there was no loss of quality associated with moving plants from either low or high temperature to high temp and light outdoors (values for all the controls being similar).

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Figure 22. Impatiens – Quality score after storage at different temperatures with plants either watered 2 hours (Con) or 24 hours (Dry) before treatment, or retaining wet foliage throughout (WetL).

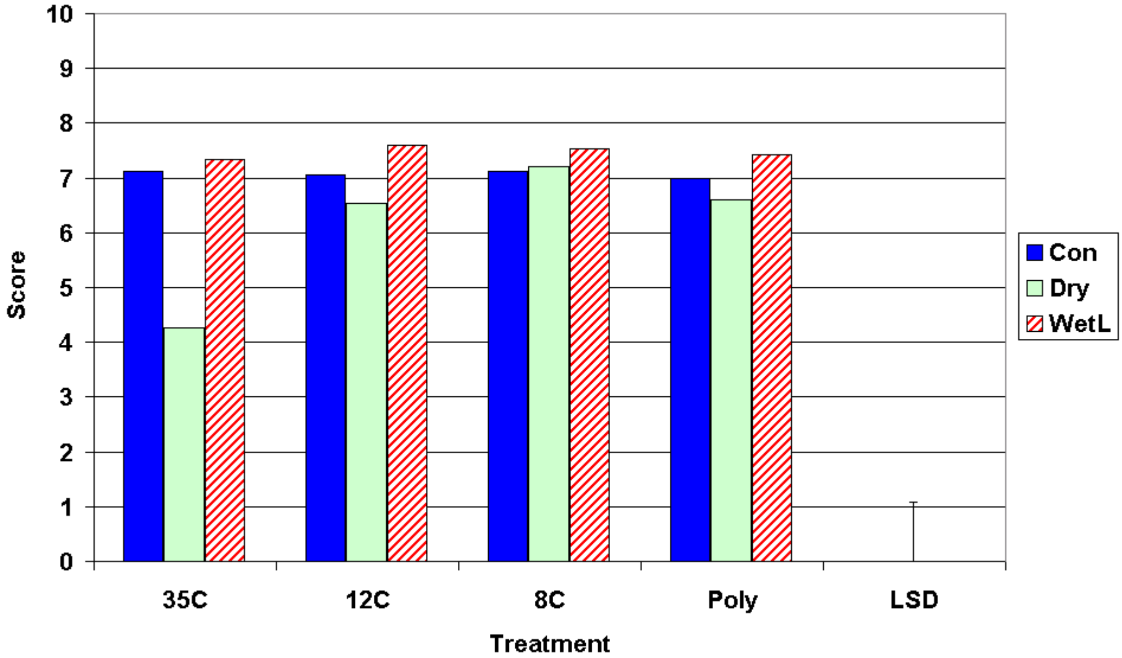


Figure 23. Impatiens – Plant health score after storage at different temperatures with plants either watered 2 hours (Con) or 24 hours (Dry) before treatment, or retaining wet foliage throughout (WetL).

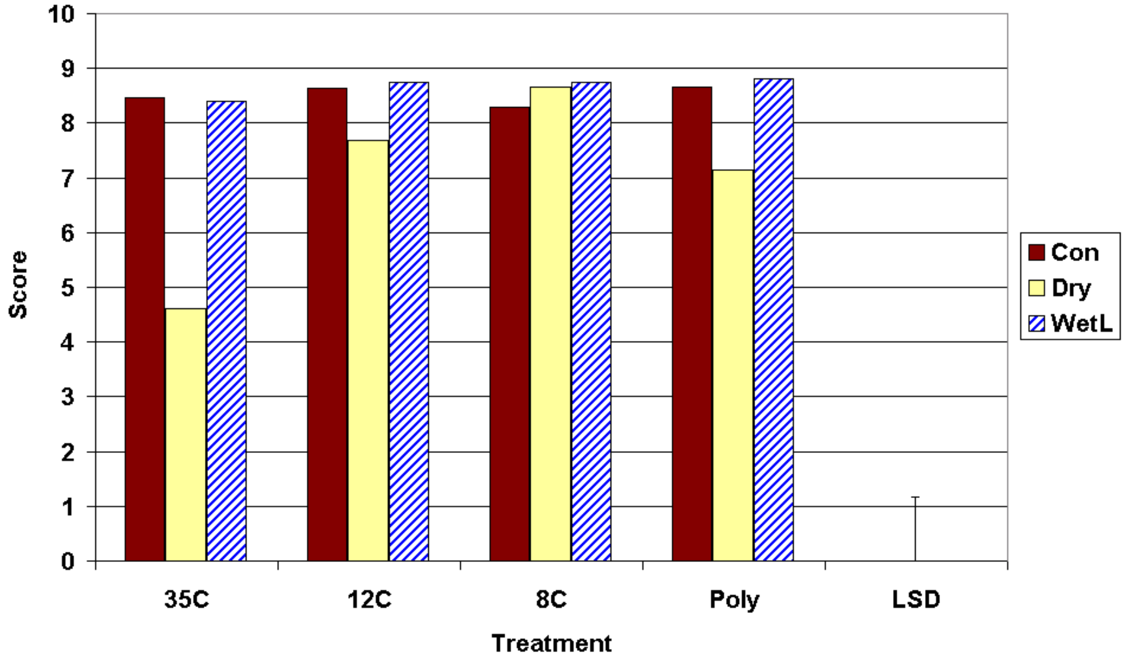


Table 8. Impatiens – Mean scores for crop uniformity, size, habit and flower development after storage at different temperatures with plants either watered 2 hours (Con) or 24 hours (Dry) before treatment, or retaining wet foliage throughout (Wet Leaves).

		Con	Dry	Wet Leaves
Uniformity	35ºC	2.34	1.80	2.52
	12ºC	2.45	2.23	2.38
	8ºC	2.23	2.52	2.27
	Poly	1.90	2.16	1.96
	LSD			0.471
Size	35ºC	1.45	1.85	1.47
	12ºC	1.56	1.71	1.75
	8ºC	1.69	1.71	1.18
	Poly	1.22	1.60	1.73
	LSD			0.633
Habit	35ºC	2.47	1.74	2.41
	12ºC	2.44	2.41	2.34
	8ºC	2.44	2.27	2.41
	Poly	2.27	2.27	2.21
	LSD			0.427
Flower	35ºC	2.71	1.91	2.97
	12ºC	2.71	2.87	2.84
	8ºC	2.84	2.71	2.97
	Poly	2.84	2.74	2.71
	LSD			0.424

Experiment 3. Controlled temperature and light combinations

This was similar to Experiment 2, but with the aim of comparing the effects of light and dark as well as rapid temperature transitions. This would help differentiate if any stress factors were linked with light rather than temperature or *vice versa*. For example, if plants were moved from the dark, cool compartment of a chilled wagon into a garden centre, would any damage found be associated with the movement to the high light outdoors or the rapid change in temperature, or even a combination of both? A range of treatments were set up to mimic a number of scenarios that could be found when trays are moved whilst on Danish trolleys.

As before we wished to explore any interactions associated with the management of the trays, in this case the possibility that some trays were not at optimum water capacity. Watering was withheld from a proportion of trays for 24 hours previous to the experiment commencing (Dry), (compared to those watered only 2 hours before - Controls).

Treatment and light combinations were:

15ºC in the light moved to 15ºC in the light (15L-15L) = Control

35ºC in dark moved to 8ºC in dark (35D-8D) = e.g. middle of trolley and moved from glasshouse to chilled wagon.
35ºC in light moved to 8ºC in dark (35L-8D) = e.g. top of trolley and moved from glasshouse to chilled wagon.
8ºC in dark moved to 35ºC in dark (8D-35D) = e.g. middle of trolley and moved from chilled wagon to garden centre (warm summer day) and left on trolley.
8ºC in dark moved to 35ºC in light (8D-35L) = e.g. top of trolley and moved from chilled wagon to garden centre (warm summer day) and left on trolley.
8ºC in dark and retained at 8ºC in dark (8D-8D) = e.g. middle of trolley and moved from chilled wagon to garden centre (cool spring day) and left on trolley.
8ºC in dark and moved to 8ºC in light (8D-8L) = e.g. top of trolley and moved from chilled wagon to garden centre (cool spring day) and left on trolley.
8ºC in light and moved to 8ºC in dark (8L-8D) = e.g. top of trolley and moved from cool dispatch area (cool spring day) to a chilled wagon.

NB Data from year 1 suggested that plants left on the middle shelves of Danish trolleys experienced effectively no photosynthetic light.

Plants were placed in each temperature x light environment for 24 hours before being assessed for quality. Cultivars used were Petunia F1 Red and Impatiens F1 White. There were 7 representative trays per treatment for each species.

Results

Petunia

Petunia quality was reduced by the Dry regime when plants were moved into 35ºC in the light (Figure 24), however, equivalent plants kept well watered were unaffected. This was largely due to some, but not all plants showing wilt symptoms under the high temperature and light conditions. Quality was also marginally lower with plants kept at 8ºC for 48 hours. This was only evident with the watered control plants and was associated with some flower damage, possibly due to the prolonged wet cool conditions in these treatments. Health scores again showed treatments were similar in maintaining plant health, with the exception of the movement of the drier plants into the 35ºC environment (Figure 25).

Scores for other quality parameters such as uniformity and habit reflect the drought stress observed in 8D-35L (Table 9). There were also low scores for uniformity and habit for 8D-8L

Con reflecting some stretching in these plants. Why the value for this 8°C treatment was marginally worse than other 8°C combinations is not clear.

There was no clear evidence to suggest that the transition in temperatures was a cause for significant loss of quality, but rather reductions in quality were due to storage duration. For example, the control values for the 8D-35L treatment did not show any signs of injury.

Impatiens

This species was particularly susceptible to loss of quality when plants had not been watered and were then placed in environments that constituted high temperatures (Figures 26 and 27). In such plants, drought stress was obvious and widespread, as reflected in some very low quality and health scores. In contrast in those plants that had been kept well-watered beforehand, there were little differences in treatment effects. Certainly, there was no evidence that moving plants from low temperatures in the dark to higher light or higher temperatures caused any injury.

As with Petunia, there was some loss of uniformity and habit associated with moving plants from 8°C in the dark to 8°C in the light, although again any obvious reason is not clear (Table 10). Flower development scores were relatively low for the 8°C well-watered treatments compared to some other treatments demonstrating delays in flower development. In contrast some of the dry and warm treatments also scored low, due to enhanced floral senescence (too much flower) in these treatments.

The results with Impatiens generally agree with those of Petunia, in that there is no suggestion that rapid transition *per se* from dark to light or from cool to warm temperatures caused damage directly.

Figure 24. Petunia – Quality score after storage and movement between different temperatures and light levels.

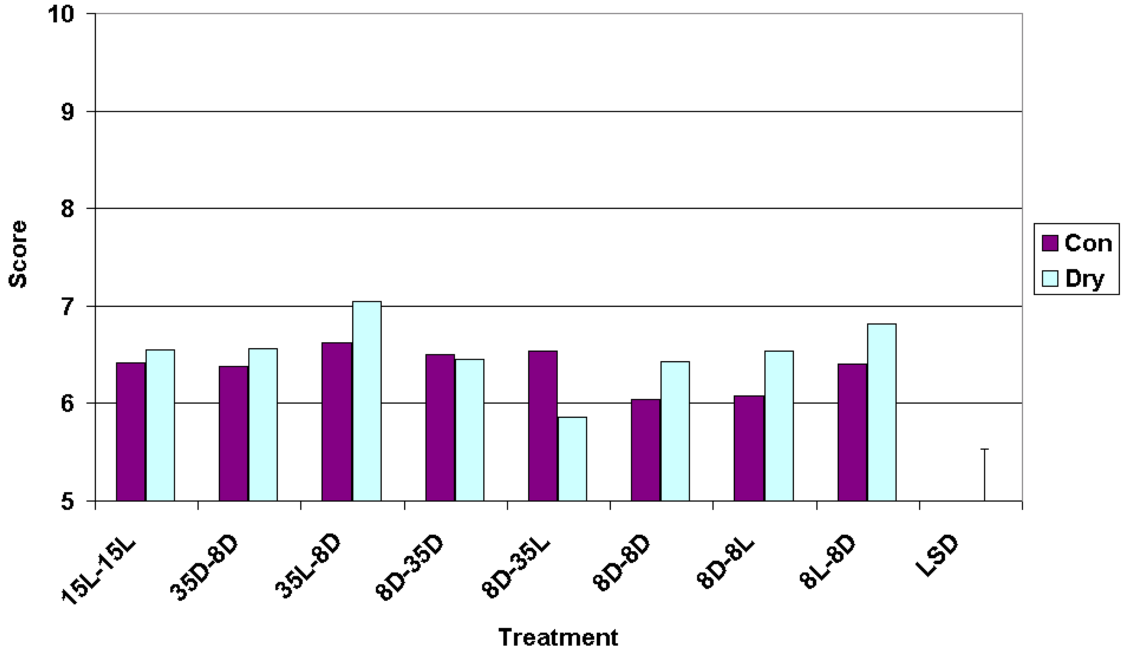


Figure 25. Petunia – Plant health score after storage and movement between different temperatures and light levels.

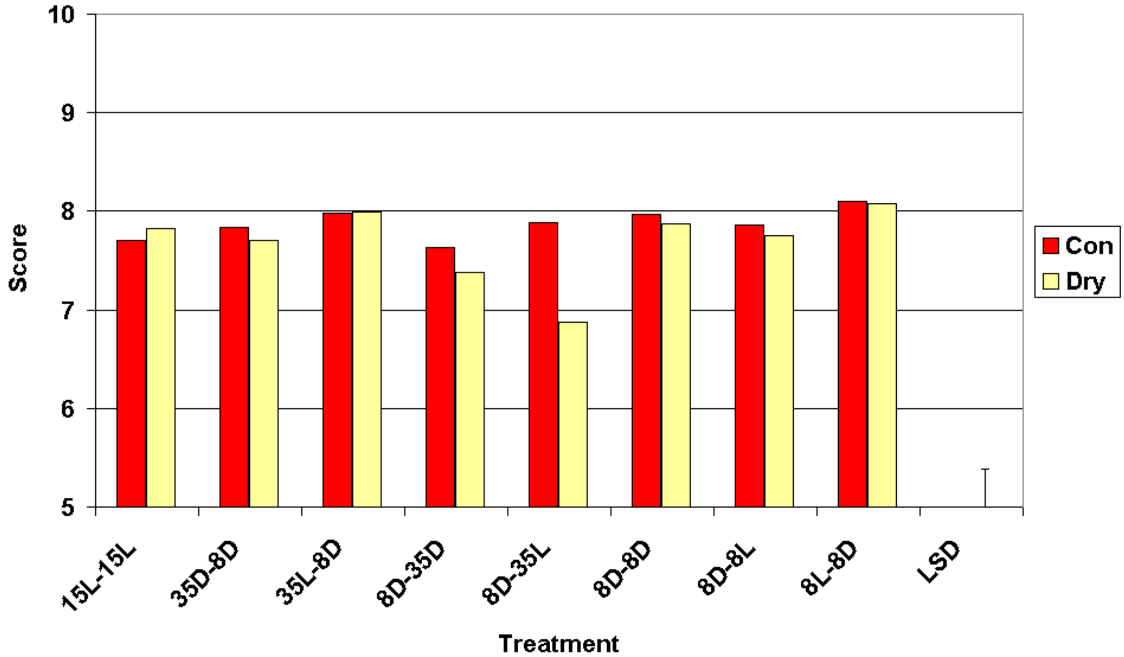


Table 9. Petunia – Mean scores for crop uniformity, size, habit and flower development after storage and movement between different temperatures and light levels.

Treatment	Uniformity	Size

	Con	Dry	Con	Dry
15L-15L	2.18	2.29	1.50	1.26
35D-8D	2.35	2.27	1.43	1.50
35L-8D	2.41	2.40	1.82	1.66
8D-35D	2.42	2.31	1.34	1.47
8D-35L	2.14	1.88	1.66	1.41
8D-8D	2.01	2.43	1.75	1.28
8D-8L	1.84	2.33	1.58	1.50
8L-8D	2.24	2.47	1.42	1.08
LSD		0.321		0.464

	Habit		Flower	
	Con	Dry	Con	Dry
15L-15L	1.90	2.12	1.18	1.18
35D-8D	2.02	1.96	1.08	1.42
35L-8D	2.27	2.31	0.99	1.42
8D-35D	1.92	2.11	1.15	1.10
8D-35L	1.87	1.66	1.32	1.27
8D-8D	1.76	2.03	1.17	1.09
8D-8L	1.66	2.16	1.32	1.25
8L-8D	1.96	2.16	1.74	1.50
LSD		0.312		0.371

Figure 26. Impatiens – Quality score after storage and movement between different temperatures and light levels.

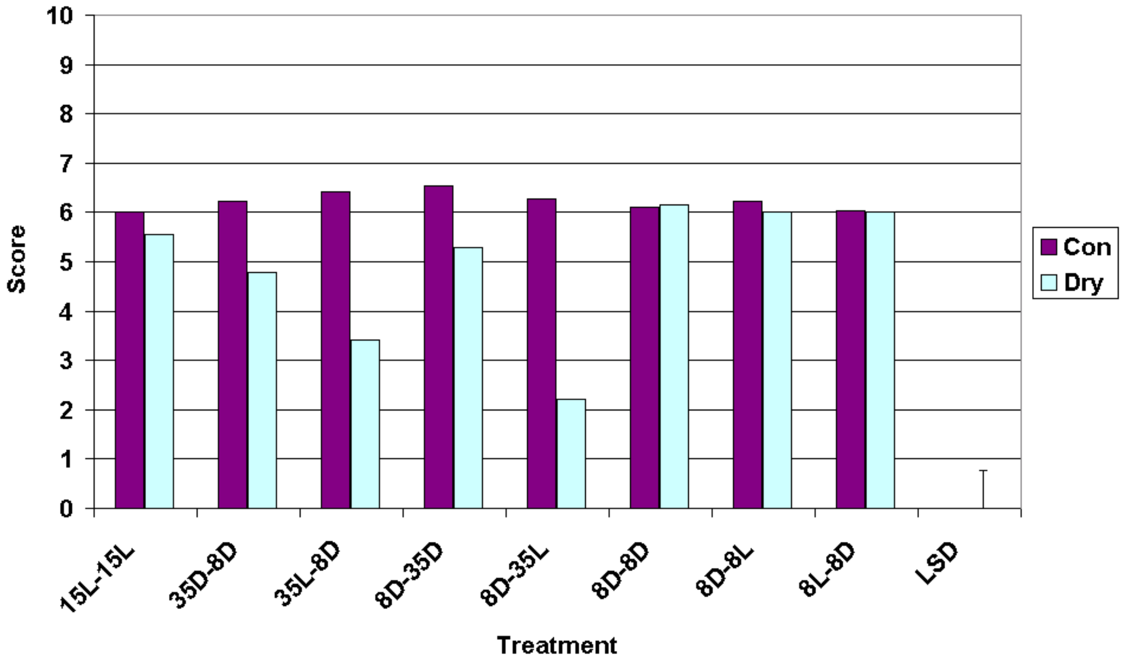


Figure 27. Impatiens – Plant health score after storage and movement between different temperatures and light levels.

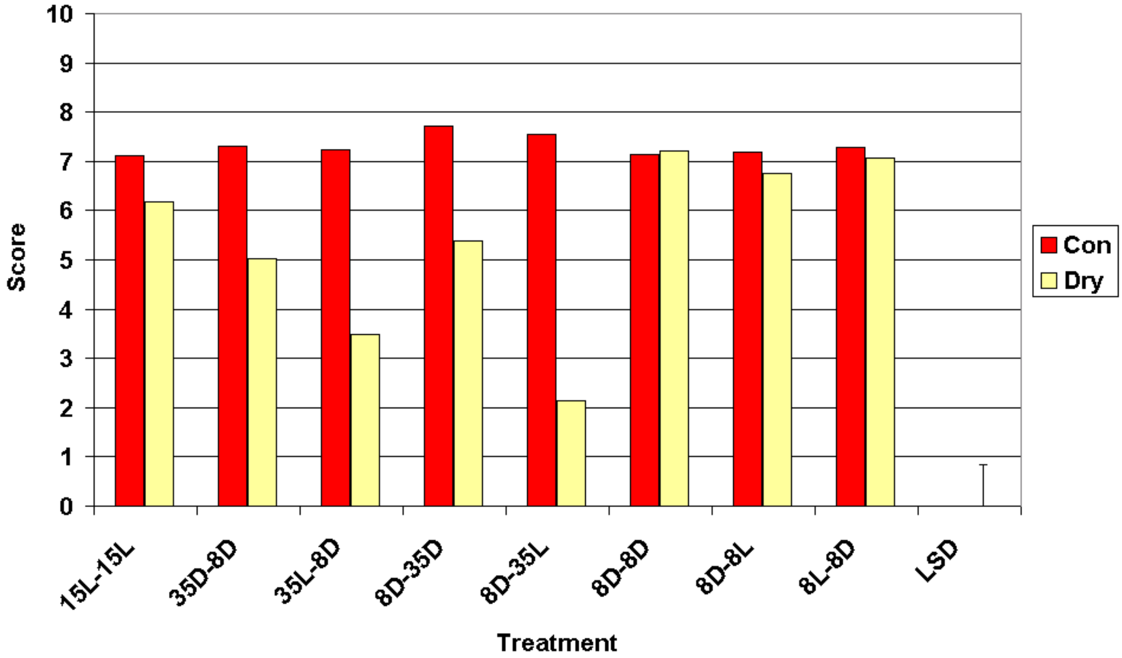


Table 10. Impatiens – Mean scores for crop uniformity, size, habit and flower development after storage and movement between different temperatures and light levels.

Treatment	Uniformity		Size	
	Con	Dry	Con	Dry

15L-15L	2.23	2.26	1.36	1.50
35D-8D	2.13	2.23	1.38	1.38
35L-8D	2.21	2.19	2.13	1.38
8D-35D	2.45	2.26	1.77	2.16
8D-35L	2.22	2.18	1.41	1.83
8D-8D	2.14	2.32	1.50	1.66
8D-8L	2.07	2.07	1.75	2.08
8L-8D	2.18	2.08	1.75	1.55
LSD		0.321		0.471

	Habit		Flower	
	Con	Dry	Con	Dry
15L-15L	2.06	1.90	1.34	2.01
35D-8D	2.08	1.86	1.92	1.92
35L-8D	2.22	1.47	2.08	1.84
8D-35D	2.21	2.01	2.33	2.50
8D-35L	2.21	1.18	2.66	1.42
8D-8D	2.08	2.14	1.66	2.09
8D-8L	1.96	2.16	1.92	1.84
8L-8D	2.31	1.93	2.00	2.42
LSD		0.339		0.524

Experiment 4. The effect of relative humidity on crop quality during transportation

It was noted in year 1 that in many cases when plants were transported in wagons humidity levels were high within the body of the wagon, especially when chilling was used and temperatures were low. In such cases high humidity and condensation were commonplace. The aim of this experiment was to determine if humidity influenced crop quality, either when transported at lower (12ºC) or higher (22ºC) temperatures. Plants were placed in controlled environment cabinets and exposed to the following treatments:

Maintained in polytunnel (Control)
12ºC 100% r.h. for 24 hours (12C H 24h)
12ºC 100% r.h. for 48 hours (12C H 48h)
12ºC 50-65% r.h. for 24 hours (12C L 24h)
12ºC 50-65% r.h. for 48 hours (12C L 48h)
22ºC 70-80% r.h. for 24 hours (22C H 24h)
22ºC 70-80% r.h. for 48 hours (22C H 48h)
22ºC 10-15% r.h. for 24 hours (22C L 24h)
22ºC 10-15% r.h. for 48 hours (22C L 48h)

As temperature itself influences humidity, values for equivalent treatments varied, with higher humidity being easier to maintain at the lower temperature. In addition to humidifying cabinets with wet wicks, plants on the higher humidity treatments were also place over wet cloths.

Petunia F1 Red and Impatiens F1 White were used with 7 representative trays per treatment combination per species.

Results

Ethylene levels did not exceed 0.6 ppm in any of the cabinets even over 48 hours, but values were notably lower in the lower humidity environments, especially at 12^{o}C (Figure 28).

Petunia

Maintaining trays of petunia for 48 hours in storage tended to reduce overall quality (Figure 29). Plants demonstrated either flaccid, dull olive coloured older leaves, or some yellowing of the new leaves. The flaccid leaf symptom was worst in the 22^{o}C, high humidity treatment for 48 hours. Overall, there was no loss of quality in any treatment after the shorter 24 hour period (Figure 29) although specific scores for plant health, even over this shorter time span suggested that high humidity (compared to the equivalent low humidity regimes) could reduce the health status of the plant (Figure 30). This was largely due to reductions in flower quality, and often plants removed from high humidity environments had a wilted appearance to their petals. This is also reflected in lower flower development scores in plants removed from high humidity (Table 11). The fact that relatively 'poor' treatments such as 22^{o}C, high humidity for 48 hours performed well on other parameters such as habit and size (Table 11), indicates most loss of quality was associated with specific leaf and petal injuries, rather than loss of shape.

Figure 28. Ethylene levels (ppm) recorded in cabinets at different temperatures and humidity, with mixed crops of Petunia and Impatiens. *NB previous research has shown that as little as 4 hours exposure to 1 ppm ethylene can be damaging to some crops.*

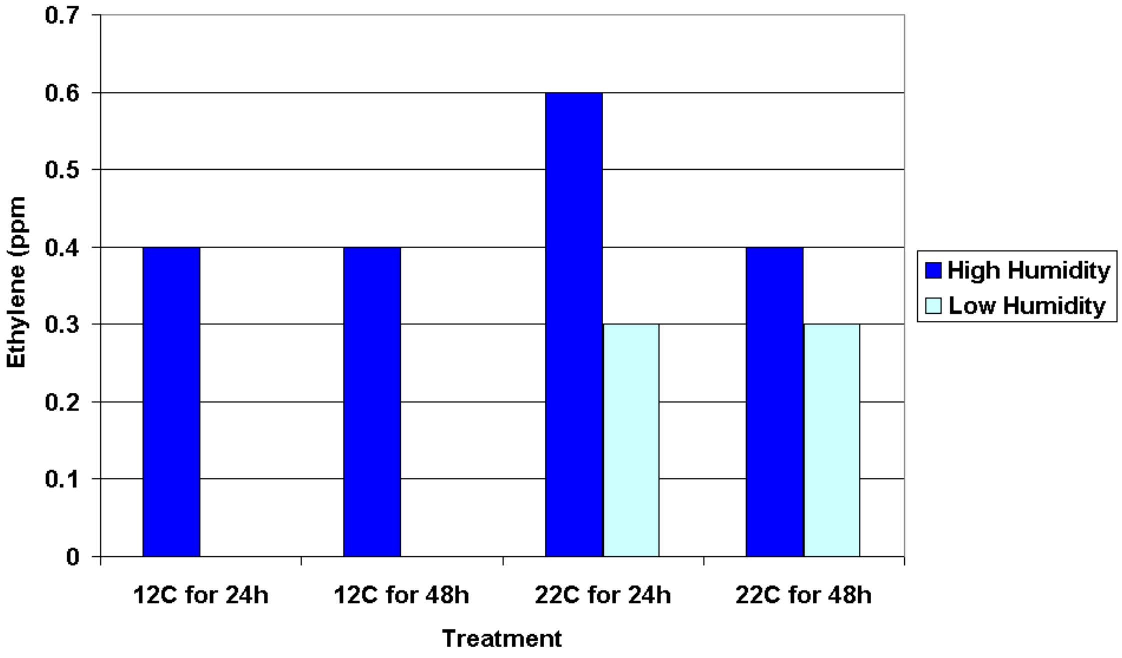


Figure 29. Petunia – Quality score after storage at different temperatures, humidity and durations.

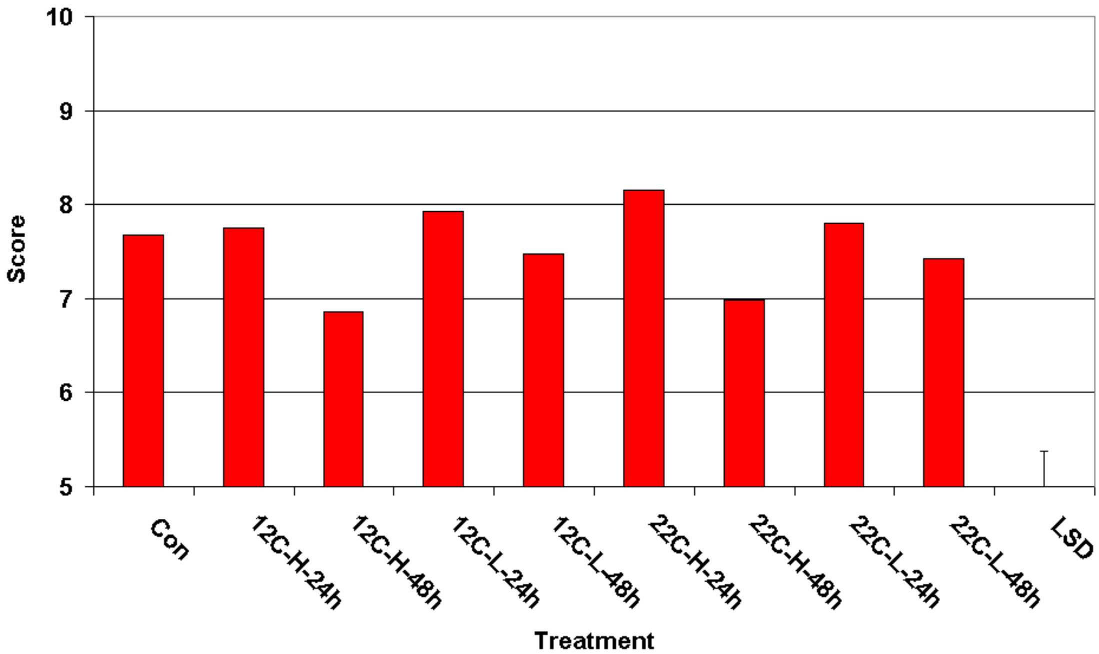


Figure 30. Petunia – Plant health score after storage at different temperatures, humidity and durations.

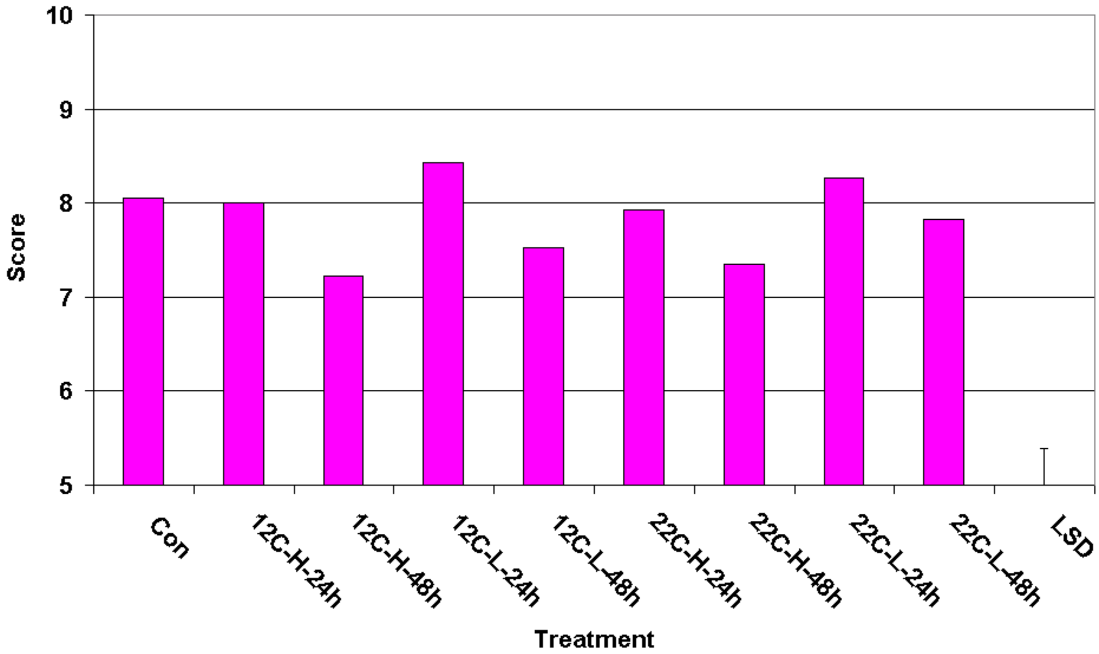


Table 11. Petunia – Mean scores for crop uniformity, size, habit and flower development after storage at different temperatures, humidity and durations.

	Con	12C		22C		LSD
		High	Low	High	Low	
Uniformity						
24h	2.04	2.05	2.48	2.23	2.10	
48 h		1.86	2.29	2.01	2.28	0.254
Size						
24h	2.07	1.72	1.93	2.12	2.02	
48h		2.21	2.07	2.26	2.21	0.446
Habit						
24h	2.18	1.94	2.13	2.22	2.18	
48h		2.14	2.23	2.14	1.99	0.268
Flower						
24h	2.28	1.61	2.08	1.80	2.46	
48h		1.48	1.89	1.13	2.19	0.405

Impatiens

As with Petunia, loss of overall quality was clearly linked with storage for 48 hours, with strongest contrast being associated between 24 and 48 hours in the higher humidity treatments (Figure 31). Injury was evident in the 22ºC, high humidity for 48 hours treatment, where some plants had yellow leaf tips and some leaf rolling of the new leaves (Figure 32). This may have influenced the plant habit assessment (Table 12). Although the trays were quite variable to start with, there was also some evidence that many of the storage treatments had affected plant size, with plants being larger (i.e. lower scores) than the controls after they had been placed in the cabinets for either 24 or 48 hours (Table 12).

Although plant quality overall was estimated to be better in the higher humidity compared to the lower humidity after 24 hours at 22ºC, the opposite was true for the health scores. Health score values were not significantly less than those of the controls, but were of the equivalent low humidity treatment (Figure 32). A small number of plants were displaying leaf shoot-tip yellowing and rolling of the new leaves in the 22ºC high humidity treatment even after just 24 hours. Whether this was an artefact of the higher ethylene readings recorded is in these cabinets at this time, remains to be determined. The effects were short-term however, and the symptoms had largely disappeared by the following assessment 24 hours later.

Figure 31. Impatiens– Quality score after storage at different temperatures, humidity and durations.

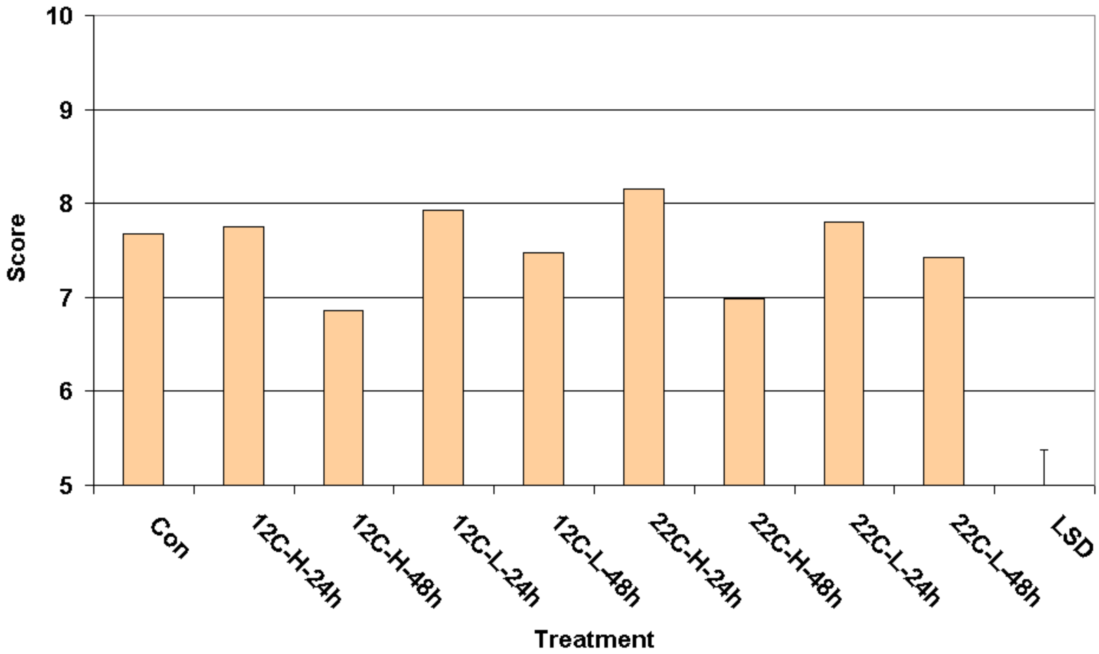


Figure 32. Impatiens– Plant health score after storage at different temperatures, humidity and durations.

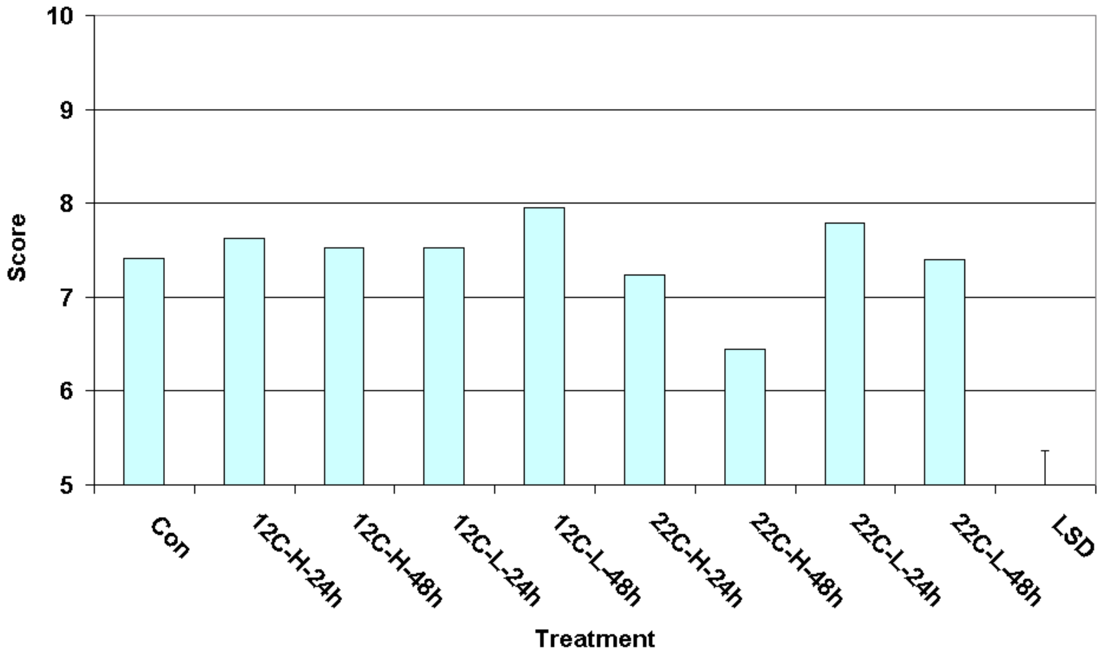


Table 12. Impatiens – Mean scores for crop uniformity, size, habit and flower development after storage at different temperatures, humidity and durations.

	Con	12C		22C		LSD
		High	Low	High	Low	
Uniformity						
24h	1.95	2.02	1.95	1.98	2.22	
48 h		2.33	2.44	1.89	1.67	0.293
Size						
24h	2.00	1.33	1.61	1.33	1.33	
48h		1.52	1.99	1.24	1.42	0.350
Habit						
24h	2.08	2.08	1.90	2.01	2.20	
48h		2.28	2.38	1.76	1.98	0.256
Flower						
24h	2.61	2.90	2.71	2.71	2.71	
48h		2.71	2.80	2.61	2.77	0.307

Experiment 5. Influence of transporting crops in polythene-wrapped Danish trolleys or in cardboard boxes

Crops of Pansy, Dianthus and Cyclamen, were placed onto Danish trolleys and wheeled into two controlled temperature environments designed to simulate wagon holds. One-third of the crop in each case was left open, one-third placed on trolleys with polythene wrapped around the trolley (leaving a gap at the top as in industry practice), and the final one-third placed in cardboard boxes (300 mm x 300 mm x 450 mm). One environment was maintained at 12^{o}C and one at 22^{o}C. Trolleys were left in the environments in the dark for 24 hours, after which ethylene levels were measured above the crop canopy in each of the treatments, and again after the crop had been moved out in ambient conditions. Plants were then placed in a polythene tunnel for subsequent assessments.

Treatment combinations were:

Control plants kept in polytunnel (Tunnel) {There was no control with pansy due to the reduced number of trays in this species}.
12^{o}C open on trolleys (12C Open)
12^{o}C in boxes (12C Boxed)
12^{o}C on trolleys covered with polythene wrapping (12C Polywrap)

22°C open on trolleys (22C Open)
22°C in boxes (22C Boxed)
22°C on trolleys covered with polythene wrapping (22C Polywrap).

Species used were Pansy F1 Mixed, Dianthus 'Festival Raspberry' and Mini Cyclamen Mixed. Each treatment was represented by 18 replicate trays except Pansy, where 13 per treatment were used.

Results

Ethylene Levels

When Pansy was placed on the trolleys, ethylene levels reached 2.0 ppm in the warm 22°C environment within the polythene wrapped trolleys. Levels were much lower in the 12°C environment, but rose once the trolleys were moved out from the controlled environment into ambient conditions (25°C) outside the cabinets (Figure 33). The Pansy crop was relatively heavy with flower (15-18 blooms per tray), whereas both the Dianthus and Cyclamen crops (placed together on the trolleys) had fewer blooms (2-3 per tray). As flowers can be a major source of ethylene, this may explain the lower ethylene levels associated with the period the Dianthus and Cyclamen were in storage (Figure 34).

Figure 33. Maximum ethylene levels (ppm) recorded at crop canopy level (pansy – heavy flowering) when trays placed either open, in boxes or on polythene wrapped Danish trolleys at different temperatures.

NB previous research has shown that as little as 4 hours exposure to 1 ppm ethylene can be damaging to some crops.

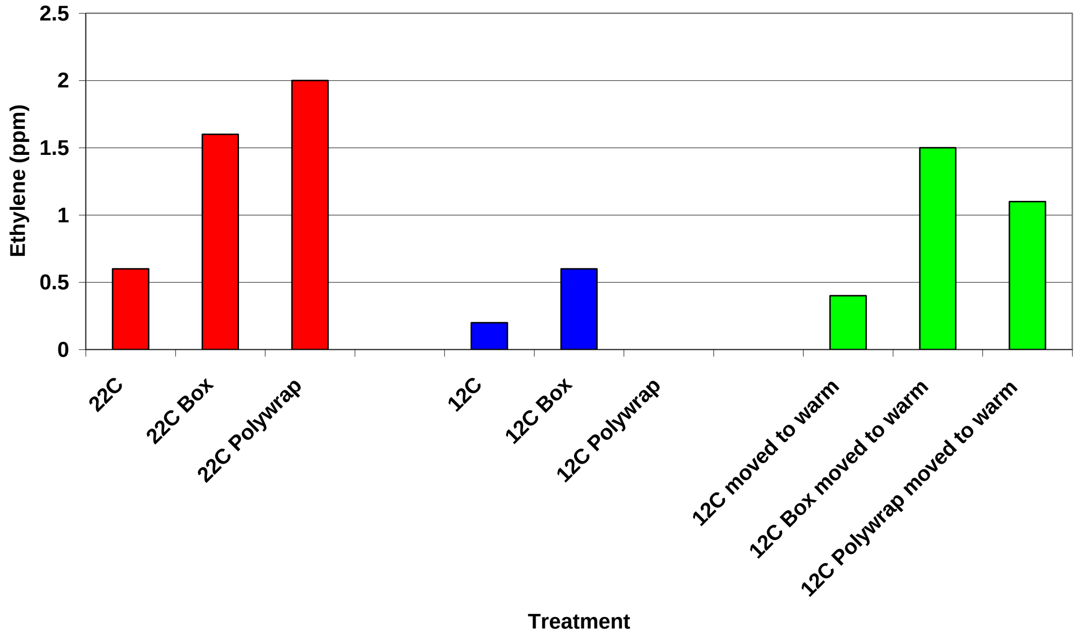
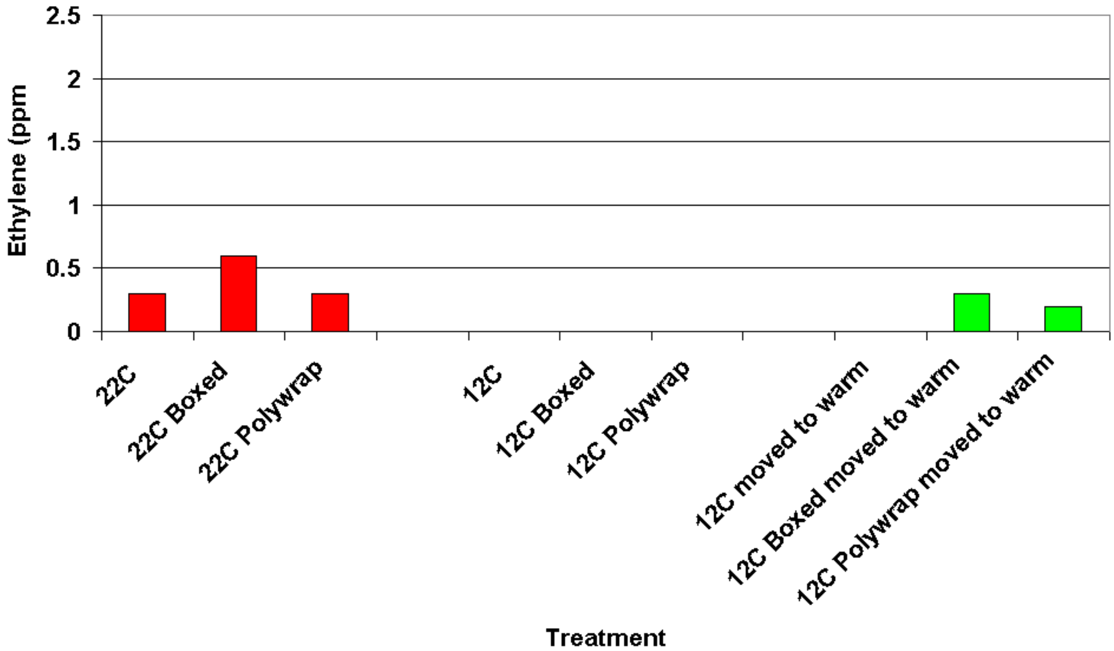


Figure 34. Maximum ethylene levels (ppm) recorded at crop canopy level (Dianthus and Cyclamen – light flowering) when trays placed either open, in boxes or on polythene wrapped Danish trolleys at different temperatures.

NB previous research has shown that as little as 4 hours exposure to 1 ppm ethylene can be damaging to some crops.



Pansy

Trays of pansy were relatively uniform and generally of good quality once removed from the treatments. There was a slight reduction in quality associated with 22ºC, but only with the Open plants, and the Polythene Wrapped and Boxed plants were unaffected compared to those plants at 12ºC (Figure 35). The loss of quality with the 22ºC Open plants was reflected in a reduced health status score, with some yellowing of leaves and stem elongation being the primary reasons in a small number of the trays (Figure 36). Poor habit was also noted for this treatment (Table 13). The reasons why the Open plants at 22ºC were worse than others at 22ºC is unclear, these plants had a very marginal lower pre-treatment score (not significant) and may also have been more affected by the air circulation fan than those enclosed in polythene or boxed. However, no similar trend was noted in the 12ºC treatment.

Figure 35. Pansy – Quality score after storage either open, within boxes or within polythene-wrapped Danish trolleys.

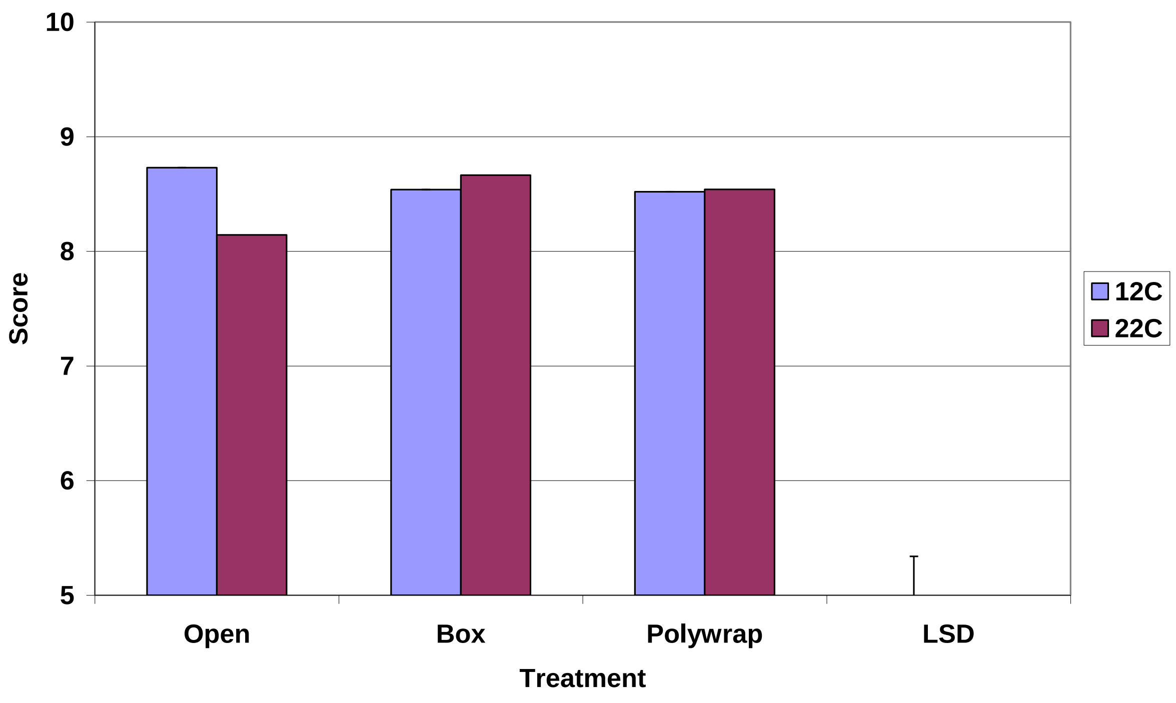


Figure 36. Pansy – Plant health score after storage either open, within boxes or within polythene-wrapped Danish trolleys.

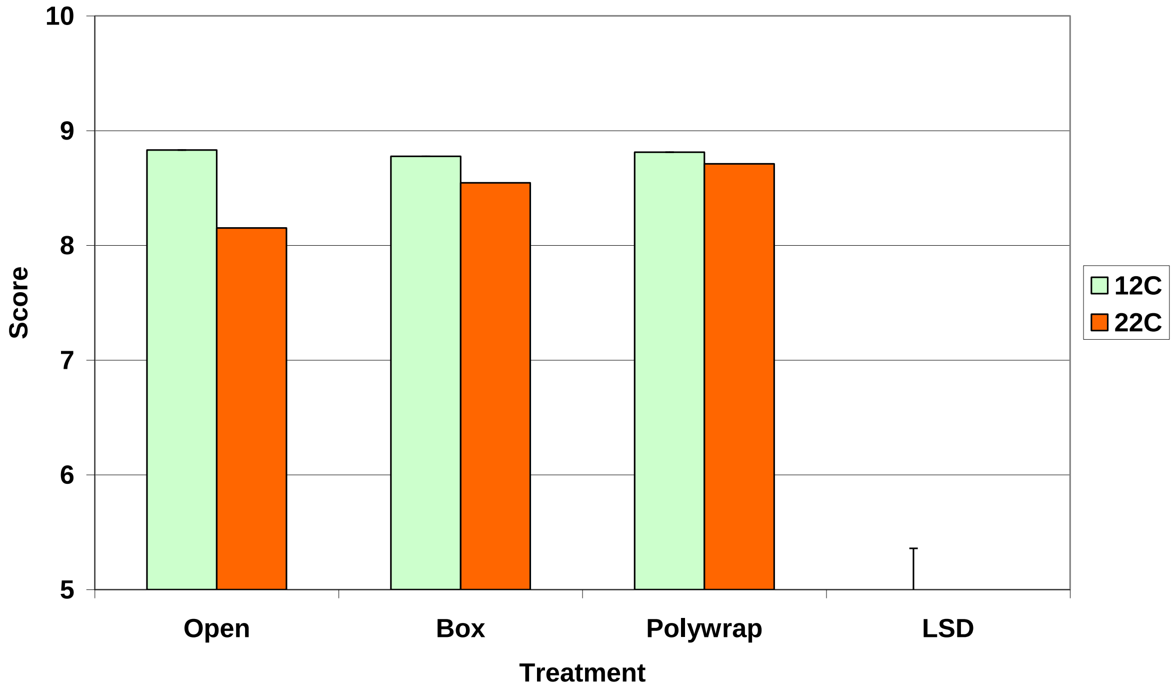


Table 13. Pansy – Mean scores for crop uniformity, size, habit and flower development after storage either open, within boxes or within polythene-wrapped Danish trolleys.

	Temp	Open	Box	Polywrap	LSD
Uniformity	12°C	1.81	1.85	1.86	
	22°C	1.77	1.84	1.91	0.186
Size	12°C	1.60	1.59	1.69	
	22°C	1.88	1.82	1.66	0.289
Habit	12°C	1.81	1.80	1.87	
	22°C	1.50	1.77	1.76	0.214
Flower	12°C	1.88	1.98	1.96	
	22°C	1.80	1.86	1.88	0.279

Dianthus

The trays of Dianthus were very uniform and compact, and all retained high quality scores regardless of the treatments imposed (Figures 37 and 38, and Table 14).

Figure 37. Dianthus – Quality score after storage either open, within boxes or within polythene-wrapped Danish trolleys.

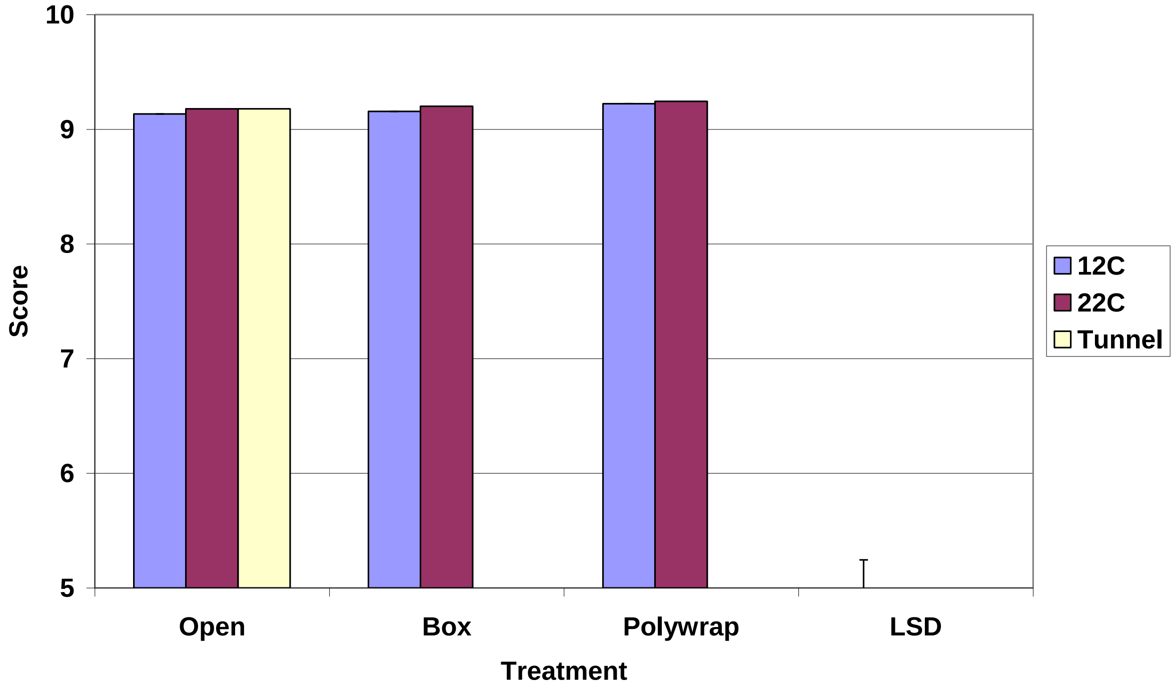


Figure 38. Dianthus – Plant health score after storage either open, within boxes or within polythene-wrapped Danish trolleys.

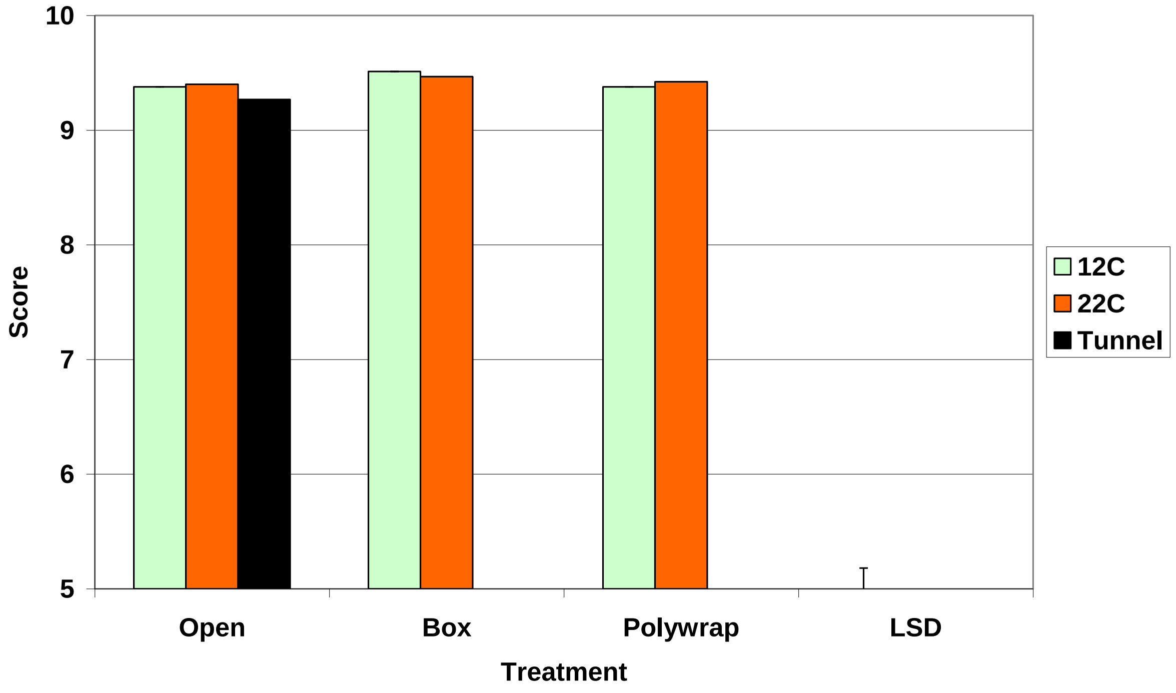


Table 14. Dianthus – Mean scores for crop uniformity, size, habit and flower development after storage either open, within boxes or within polythene-wrapped Danish trolleys.

Temp	Open	Box	Polywrap	LSD

Uniformity	12ºC	2.69	2.46	2.50	
	22ºC	2.53	2.40	2.66	
	Tunnel	2.69			0.402
Size	12ºC	3.00	3.00	3.00	
	22ºC	3.00	3.00	3.00	
	Tunnel	3.00			NA
Habit	12ºC	2.47	2.53	2.67	
	22ºC	2.53	2.47	2.60	
	Tunnel	2.60			0.411
Flower	12ºC	2.72	2.89	2.92	
	22ºC	2.97	2.79	2.92	
	Tunnel	2.78			0.280

Cyclamen

As for the Dianthus, the trays of Cyclamen were of a high quality prior to treatment and remained in a saleable quality after all the storage regimes. There was a slight reduction in overall quality, however, associated with the 12ºC Polywrap treatment (Figure 39), largely to a poor growth habit in a small number of the trays (Table 15). There were also some limited incidences of *Botrytis* and leaf yellowing associated with the 22ºC Boxed plants (Figure 40).

Figure 39. Cyclamen – Quality score after storage either open, within boxes or within polythene-wrapped Danish trolleys.

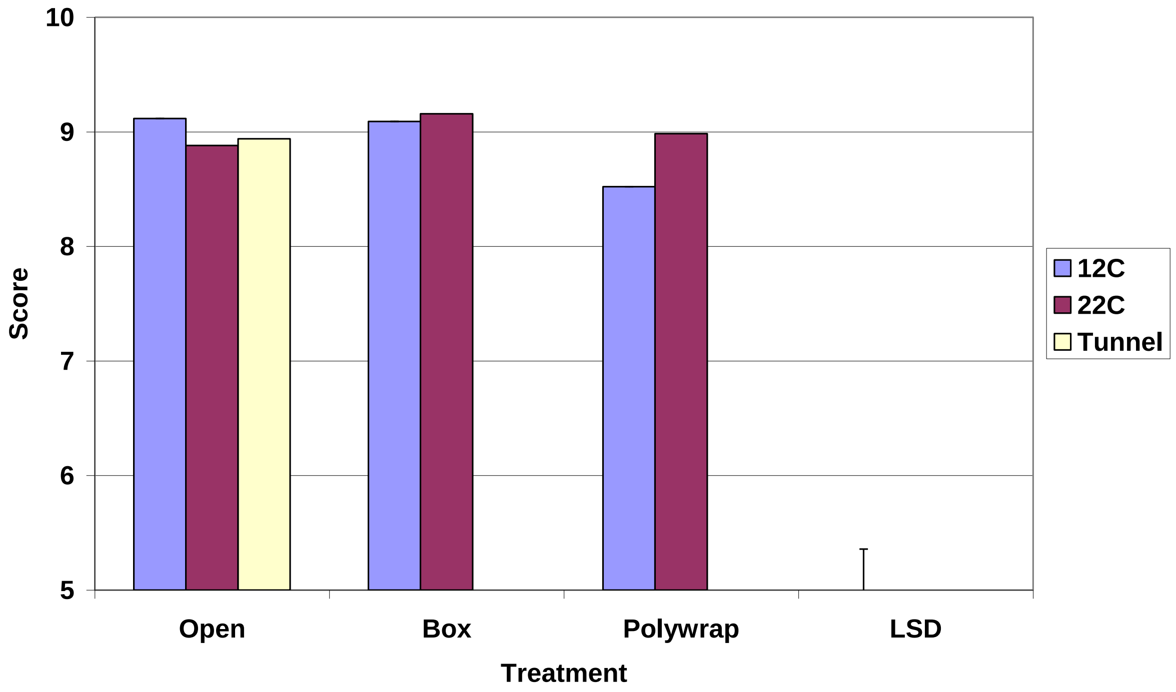


Figure 40. Cyclamen – Plant health score after storage either open, within boxes or within polythene-wrapped Danish trolleys.

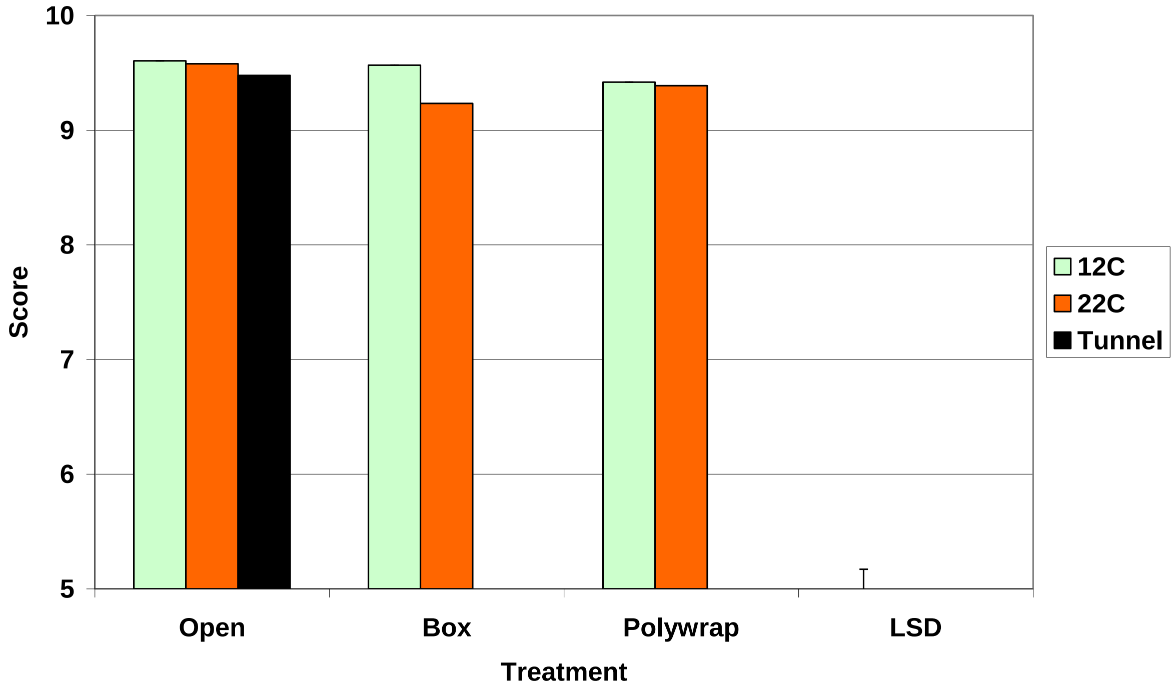


Table 15. Cyclamen – Mean scores for crop uniformity, size, habit and flower development after storage either open, within boxes or within polythene-wrapped Danish trolleys.

Temp	Open	Box	Polywrap	LSD

Uniformity	12ºC	2.39	2.39	2.62	
	22ºC	2.27	2.39	2.24	
	Tunnel	2.24			0.460
Size	12ºC	2.99	2.73	3.00	
	22ºC	3.00	2.75	2.99	
	Tunnel	3.00			0.272
Habit	12ºC	2.45	2.38	2.08	
	22ºC	2.46	2.37	2.28	
	Tunnel	2.32			0.445
Flower	12ºC	2.14	2.09	2.07	
	22ºC	1.92	2.27	2.32	
	Tunnel	1.78			0.600

Conclusions

Most of the injuries noted and instances of loss of quality were associated with storage for 48 hours, with a number of crops demonstrating detrimental effects linked with this prolonged period of enclosure. Storage in the warmth (22ºC) often resulted in reduced scores compared to cooler storage for the same period. Crops that showed adverse effects with prolonged warm treatments were Pansy (both winter and spring varieties) Petunia, Cyclamen and Impatiens. In addition to elongated shoots and subsequent loss of uniformity and habit, plants often had characteristic yellow colouration to the new shoot tips or leaves. Such symptoms are typical of lack of light, although in a number of cases the effects of ethylene cannot be discounted as this too can result in leaf yellowing.

The use of cooler temperatures could not guarantee that quality would be retained over the longer storage durations of 48 hours. Cyclamen, Polyanthus and in some cases Petunia exhibited loss of quality within 48 hours at 12ºC or 8ºC.

Although these results are interesting, it is fairly logical to assume that longer storage is likely to be more damaging than shorter periods. It is noteworthy, however, that quality regularly deteriorates between 24 and 48 hours, and this may highlight some issues for the longer transport runs within the UK.

More worrying, and probably more relevant to most haulage companies, though is the case of injury or loss of quality after only 24 hours. Petunia lost quality after only 24 hours, with poor plant size and habit scores in one experiment. Petunia flowers which appear particularly susceptible to wetting and high humidity could also deteriorate after 24 hours, when exposed to high humidity (both at 12ºC and 22ºC).

There were also some suggestions of small quality reductions when plants were held on Danish trolleys for 24 hours (Experiment 5), although there was no consistent trend with treatments across species, i.e. the most stressful treatment for Pansy was 22ºC in the open trays; whereas both 12ºC polythene wrapped (loss of growth habit) and 22ºC boxed plants (*Botrytis*) marginally reduced quality in Cyclamen. In contrast, the Dianthus stored particularly well over 24 hours.

Storage of the crop with wet foliage / flowers could be detrimental in some scenarios, but responses were not consistent across the species. Impatiens was impervious to leaf wetting, whereas there were instances when foliar wetting had a negative effect on plant habit and size in Petunia (at 22ºC) and to some extent Polyanthus (Experiment 1). Flowers were often more prone to injury than foliage, e.g. Petunia, Cyclamen and Pansy all showed some flower damage when stored wet.

As Impatiens appeared unaffected by leaf wetting, it was surprising to detect that high humidity had some influence on its quality. In Experiment 4, injury was significantly greater under high humidity compared to low humidity when plants were stored at 22ºC (Figures 31 and 32). Petunia too, responded negatively in terms of quality to the higher compared to the lower humidity regimes. One of the clearest symptoms of this, although not the only one, was flower quality. Petunia flowers often possessed a flaccid, wilted appearance on removal from high humidity environments, regardless of storage temperature.

Watering remains a challenging area for the grower. As outlined above, wet foliage, under the wrong environmental conditions may be detrimental in some species. The consequences of not watering prior to shipment, however, may be even more damaging. The largest loss of plant quality in Impatiens was due to drought stress, when the trays had not been irrigated for 24 hours prior to treatment and plants were subsequently placed into the higher temperature environments. The safest strategy would appear to be to water the crop well at dispatch, but a couple of hours before placement on the wagon to provide time for most of the droplets on the foliage / flowers to evaporate prior to the crop being 'closed up'.

There were a number of encouraging findings from the experiments carried out in year 2 of the project. We found little evidence that rapidly moving plants from cool dark conditions to bright sunlight and high temperatures was damaging. In three out of four cases, well-watered plants were undamaged when moved from low to higher temperatures, or from dark to light. The one exception was with Petunia plants kept at 12ºC then moved to outdoor conditions, which scored relatively poorly (Experiment 2). This may have had more to do with the quality of the plants in the first place and the previous 24 hours storage, however, rather than the rapid temperature/light shift *per se*. A caveat to this experiment though was that when plants were moved directly outside, air temperatures were only 29ºC, i.e. not as warm as can be experienced during sunny periods in mid-summer.

In Pansy there were no negative effects on crop quality associated with transporting bedding plants on trolleys either enclosed in cardboard boxes, or with the trolley shrink-wrapped with polythene. This was despite recording relatively high ethylene readings in both the boxes (1.5 ppm) and within the polythene wrapping (2.0 ppm) when crops were stored at 22ºC. Dianthus too showed no negative effects after polythene wrapping or being enclosed in boxes. The situation was more ambiguous with Cyclamen; all the trays of plants were deemed to be still saleable at the end of the trial, but there were small (but significant) reductions in quality associated with the polythene wrapped plants held at 12ºC. There was also a limited amount of leaf yellowing and *Botrytis* associated with plants stored in boxes at 22ºC. *Botrytis* was also problematic in this crop in Experiment 1, especially when plants were held wet at 12ºC for prolonged periods, and this aspect may merit further investigation.

Generally, recordings of ethylene evolving from the crops followed patterns similar to those found in year 1. Higher ethylene values correlated with higher air temperatures (and humidity) and levels could vary depending on the species or even cultivar being measured. One interesting point to note, however, is that ethylene levels did not always increase with duration of storage. Recorded values could be lower after 48 hours storage compared to 24 hours, primarily because a proportion of the crop had been removed from the cabinet. Crop density and volume of flower present may be more critical factors that storage duration.

Overall the results from year 2 suggest that loss of crop quality is feasible through the transport process, but it is most often expressed at the extremes of the environmental variables likely to be encountered in practice. Growers involved with shipping their crops over long distances (i.e. longer durations, e.g. greater than 24 hours) or at higher storage temperatures may be those most at risk. Also, as with cultivation and husbandry issues, there may also be inevitably crop specific problems that growers will encounter. Loss of quality in Petunia flowers with wetting and high humidity may be an obvious one, however, reductions in quality and exacerbation of disease problems with 12ºC storage in Cyclamen may be less well recognised.

Technology Transfer

Data from year 1 was presented at the HDC / BBPA AGM and Grower Conference (New Crops and New Technologies, Oxford,8th Feb 2007) and illustrated in HDC News 130 (Feb 2007).

Glossary

Chlorophyll Fluorescence: A techniques that measures the photochemical efficiency of leaf, i.e. how quickly light energy can be converted into chemical energy during photosynthesis. When this process is impaired (e.g. when leaves experience stress) more energy is re-emitted from the leaf as fluorescence light, rather than used to drive photosynthesis within the chloroplasts. By measuring the parameters of the fluorescence light signal, factors such as maximum chlorophyll fluorescence (Fm) and variable fluorescence (Fv) can be calculated. The ratio Fv /Fm is often used as an indicator of leaf damage, with ratios < 0.7 often suggesting significant injury.

Acknowledgements

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