# 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

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**Final Report**

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The results and conclusions in this report are based on a series of experiments conducted over a three-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.

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### Headline

Length of transportation ‘run’ appeared the most critical factor influencing bedding plant quality, with injury evident in a range of crops after 48 hours. However, even after 24 hours, loss of quality could occur if additional negative factors such as relatively high storage temperature (22ºC) or high humidity were present. Pre-conditioning plants through controlled irrigation, lower growing temperatures or a single growth regulator application prior to distribution helped retain crop quality.

### 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 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 potential litigation. This research aimed 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 of the project and main conclusions

- Bedding plant crops are susceptible to a range of stress factors during transportation.
- In most cases the crops are not in transit long enough for these factors to become critical.
- There are exceptions, however, and these may be the scenarios that account for crops being rejected (occasionally) on arrival at the retailer.

***Temperature and storage duration***

- Both refrigerated and non-refrigerated wagons were commonly used to transport bedding.
- The majority of transport runs in commerce were recorded at temperatures between 11$^{o}$C and 16$^{o}$C, although some runs in summer were warmer at 18-21$^{o}$C.
- Controlled experiments indicated that storage in the warmth (22$^{o}$C) often resulted in reduced quality compared to cooler storage for the same period. In general, temperatures in excess of 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.
- 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 with this prolonged period of enclosure.
- Crops that showed adverse effects in prolonged warm conditions 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.
- Overall, shorter-term storage at lower temperatures (10-12$^{o}$C) tended to be the optimum treatment for most species.
- The use of cooler temperatures could not always 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 in the controlled experiments.
- Injury and loss of quality after 24 hours storage was less common, although some species (e.g. Petunia) still demonstrated significant reductions in quality.
- Variation can occur between the temperature a driver believes the crop is held at and the actual temperature, (possibly by as much as 4$^{o}$C).
- On moving plants during transit they can be exposed to rapid transitions of temperature and humidity (e.g. from 11$^{o}$C to 35$^{o}$C in a few minutes). We found little evidence, however, that rapid changes *per s*e caused direct injury.

***Light, Humidity and Ethylene***

- During transportation, plants are effectively in the dark, for periods of up to 48 hours (and possibly longer although this was not recorded). According to the literature 36-48 hours in darkness is at about the limit for some bedding plant species.
- Data from wagons showed that relative humidity may be 100% across a range of temperature regimes. This is a concern as experiments showed high humidity can be detrimental to crop quality e.g. Petunia and Impatiens; the former species

demonstrating effects after just 24 hours. Flowers were particularly susceptible to high humidity (both at 12ºC and 22ºC - Photo 1).

**Photo 1. 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.**

- Sensitivity to ethylene during transportation is strongly dependant on cultivar, exposure time, temperature and even carbon dioxide levels.
- Levels of ethylene recorded in commercial crops 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. There was 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.

***Water***

- Watering of the crop is an issue for concern – there were examples of commercial crops arriving at their destinations with dry growing media (beginning to wilt) and crops with foliage (and flowers) drenched in water.
- 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.

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

***Pre-conditioning treatments***

- Reduced watering *during production*, however, was promising in terms of improving plant quality, and although plants were required to be well-watered prior to transportation, these plants tended to retain their quality.
- Growing the crop at cooler temperatures (2$^{o}$C less), brushing the crop and applying a single chemical growth regulator were also promising techniques for maintaining quality during transportation.

**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**

- Growers / retailers need to recognise that light levels at dispatch points, hubs etc. are probably not contributing to any energy gain in the crop. (i.e. the plants have the potential to start deteriorating once removed from the growing environment). Crops need to be moved through dispatch and transportation stages as quickly as possible. Avoid transportation runs > 48 hours.
- Where practicable, plants should be removed from Danish trolleys by the retailer, as light levels are so low in the middle that plants will quickly stretch and deteriorate.
- Water well before loading (e.g. 1-2 hours), but allow foliage to dry before being placed on wagons.
- Growers and retailers need to be careful to avoid external sources of ethylene. Damaged crop material and petroleum / diesel powered machinery needs to be eliminated from any crop growing or handling environments.
- Ethylene itself is produced in some food and flower crops and growers need to be sure that bedding plants are not being placed in environments that may have residual high levels of ethylene (e.g. Ethylene can remain absorbed onto the walls and other hard surfaces of the lorry wagon). Take action to avoid mixed crop types and enquire from haulage companies what previous loads were, if you have any concerns.

- Hauliers need to be aware that temperature settings on wagons may not be particularly accurate and that temperatures can be 3 to 4ºC different from the set point.
- Avoid shipping crops at temperatures ≥ 20ºC. Detrimental effects due to ethylene, lack of light and high humidity are worse at higher temperatures.
- Care needs to be maintained when transporting chilling sensitive species (e.g. Impatiens, Marigold or Zinnia) in mixed loads, as wagon temperatures may be low enough to cause chilling injury.
- Ensure crops are disease free before transport; high temperatures and humidity will encourage disease development and spread.
- 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 open flower present.
- Keep the crop as cool as possible during the latter stages of production by using the glasshouse's ventilation systems. A 2ºC drop in mean air temperature was enough to improve crop quality in all three species tested in Year 3.
- Consider using irrigation to regulate crop growth more effectively-, if necessary, invest in more precise and uniform distribution systems.

- Beware the excessive use of chemical growth regulators during production – plant quality was often reduced by over-use of such materials. On site trials will be required to gain confidence in application rates and timing to specific crops.
- Over-application of plant growth regulators may also impact on garden performance (not tested). Very compact plants induced by growth regulators applied on 3 separate occasions, remained ‘dwarfed’ for a number of weeks afterwards.

# Science Section

## Introduction

Maximising and maintaining quality of a bedding plant crop is a key issue for growers, not only to ensure customer satisfaction for a given sale, but also to maintain customer / retailer confidence and loyalty in the product in future. Bedding plants being a living product are particularly vulnerable to injury from inappropriate environments or handling and even relatively short periods in sub-optimal conditions can result in reductions in crop quality. Thus to ensure customer satisfaction, growers not only have to produce a high quality crop in the first instance, they need to be able to ensure it reaches the market place without deterioration.

Although the majority of bedding reaches market in good quality, anecdotal evidence suggests loss in crop quality can occur on occasions, and batches can be rejected by retailers. 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.

Previous research has confirmed that high quality plant material can suffer significant reductions in quality over short time intervals when transported in commercial vehicles (Langton *et al*., 2002; Edmondson and Parsons, 2005). A key element identified in HDC PC 200 was that bedding plants in flower can leave a nursery in good quality, yet arrive at the retail site with a considerable reduction in quality. Armitage (1993) estimated that as a result of poor handling during transit and retail, up to 20% of floricultural products in the USA could become damaged, reduced in price or even become unsaleable. 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). Also an improved understanding of the factors that influence crop quality during transportation, will help clarify where responsibility lies, should crops be rejected and litigation procedures take place.

This research aimed 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. The research was divided into 2 phases:

1. Data acquisition from commercial transport and distribution chains, investigating typical variations in temperature, humidity, light and ethylene levels that occur from the point of dispatch on the nursery through to the point of sale. (Year 1)
2. Using controlled environmental facilities, clarify which environmental variables are critical in determining crop quality and whether there are practical techniques growers and transport companies might adopt to improve crop robustness and minimise the effects of stress post-production. (Years 2 & 3).

During Year 1 (Phase 1) the dynamics of bedding plant transport in commerce were studied in an attempt to collate information on:

- The range of temperatures and humidities experienced in the transport and distribution chain over the course of a year, and identify the frequency of extremes.
- Common handling protocols that influence exposure to light, water availability or leaf wetting.
- The types of transport commonly used (e.g. lorry size, presence of temperature control etc.) and typical duration of transport 'runs'.
- Crop exposure to ethylene during transport / distribution and its possible impact on bedding species.

In an attempt to put the information gained in context, a review of the literature was carried out covering previous research into the transport of bedding and other ornamental plants.

**Review of current literature relating to the transport of bedding plants and other ornamentals**

Previous research dedicated solely to the transport of bedding plants is limited, certainly compared to the literature relating to pot-grown ornamentals (flowering and non-flowering) used primarily as house-plants. Armitage (1993) states that less than 5% of research dealing with post-production quality in ornamentals actually involves bedding plant species. Despite production systems often being different between pot-plants and bedding (esp. modular or pack bedding), important information can be gleaned from data on the transport of pot-plants. As such, relevant information from the pot-plant sector is included in this review, and where appropriate used to address some of the problems encountered with the transport of bedding plants.

*Bedding plant studies*

Experiments focused exclusively on the transport of bedding material have been carried out primarily by the University Extension services in the USA. For example, Armitage (1993) highlighted temperature and ethylene as being the key factors that bedding species are likely to be vulnerable to during transit and retail. He divided species into 2 groups based on temperature optima:- 10-13$^{o}$C for e.g. *Calendula officinalis*, *Viola x wittrockiana* (pansy), *Petunia x hybrida* and 15-17$^{o}$C e.g. for *Begonia semperflorens*, *Impatiens wallerana, Celosia plumosa*. These groupings appear to align closely with differences in chilling tolerance between the species. Although Armitage (1993) advocates keeping temperatures cool during shipping, the temperatures he recommends are higher than those recommended by Nell and Reid, (2000) for comparable species. For example, these authors claim that pansy and *Petunia* can be stored at 2-4$^{o}$C, *Begonia* 2-13$^{o}$C and *Impatiens* 10-16$^{o}$C. Indeed, they claim that in the USA

"Temperature during storage and transportation are too high in the industry today"

In this scenario, however, they are discussing all ornamental crops, cut flowers, pot-plants and bedding. Nevertheless, there seems to be some ambiguity, about specific temperatures for individual bedding plant species.

Excessively high temperatures can cause reduced shelf-life and loss of quality (see later section), but specific studies on bedding are limited. High temperature (20$^{o}$C) during post-production stages was cited as causing plant collapse in *Primula*, although only in one, red flowered variety (Høyer and Kristensen, 1991). In this particular study, the authors suspected that that root damage induced by sciarid fly larvae during production was the cause, but that this was only expressed when plants were later placed under warmer temperatures during transit. There was no wilting when other plants were kept at 13$^{o}$C.

Armitage (1993) also alludes to the effects of ethylene, although data on commercial crops has not been quantified. Nevertheless, experiments under controlled environments showed that there were variations in sensitivity to ethylene between species. For example, *Calendula officinalis*, *Lobularia maritima* (alyssum), *Tagetes* spp. (marigold), *Zinnia elegans* were considered insensitive; *Begonia semperflorens*, *Solenostemon scutellaroides* (coleus) and *Petunia x hybrida* classed as moderately sensitive and *Impatiens wallerana*, *Pelargonium x hortorum* (geranium), *Salvia splendens* and *Antirrhinum majus* as highly sensitive to ethylene (Armitage, 1993; Smith, 2001). Results also indicated that higher transportation temperatures and poor ventilation would increase the risk of ethylene injury. Most research studies support this position (see section on other crops types), but one study on *Petunia* suggested that in this species at least, lower growing temperatures (17$^{o}$C day / 12$^{o}$C night) were associated with higher ethylene production (Shvarts, *et al.*, 1997). Ethylene concentrations as low as 0.01-5 ppm (= 0.01-5 μl $l^{-1}$) may induce injury in some species (Willumsen and Fjeld, 1995) but extent of damage is often a function of exposure time, highlighting the need for good ventilation during transport and storage (Høyer, 1984).

In his review of bedding plant production, Armitage (1993) ranked the factors that strongly influenced post-production quality and divided these between production issues and handling and transport issues. Although some of these factors may relate to conditions in the USA, they are a useful reference point for this study (Tables 1 and 2).

The lack of watering during post-production stages and hence loss of quality through drought has been a concern for many bedding plant growers, especially since there is limited volume of media associated with most pack and other bedding plant containers. The use of wetting gels and surfactants have been investigated, both in an attempt to retain moisture in the peat based media, and to help re-wetting at the retail stage. Million *et al.*, (2001) working on *Chrysanthemum* and *Petunia* concluded that surfactants needed to be added as a drench immediately prior to shipping the crop, to obtain any effect.

Armitage (1993) claims the effects of adding wetting gels is non-conclusive, but that the addition of soil or green compost (e.g. *Impatiens*; Klock-Moore, 2001) to the medium may help water retention and avoid hydrophobic conditions in the peat. Antitranspirants applied to the foliage of bedding species has been attempted too, but with only limited success in extending shelf-life (Gehring and Lewis, 1980). Snider *et al.*, (2003) however, claimed that spraying *Impatiens* with lysophosphatidylethanolamine (LPE), a natural occurring lipid, increased flower retention after drought stress. The use of buffered phosphate fertilisers applied during production has also been cited as improving tolerance to drought, through their action of extending root proliferation within the module and promoted more compact shoot growth, i.e. lower transpiration rates (Borch *et al.*, 1998; Borch *et al.*, 2003). More recent studies (Blanchard *et al.*, 2007) illustrated increased tolerance to drought and prolonged shelf life quality when abscisic acid (ABA) was applied to bedding crops (125 or 250 mg·$l^{-1}$ per pot). ABA extended the marketability of *Catharanthus roseus, Impatiens hawkeri, Pelargonium* ×*hortorum, Petunia* × *hybrida* and *Verbena* ×*hybrida* . It had no effect, however, on *Sutera cordata* and *Impatiens walleriana*, and induced phototoxicity symptoms on *Viola* ×*wittrockiana* and *Lobelia erinus*.

**Table 1. Production factors that influence bedding plant shelf life (5 = very important; 1 = little importance) (reproduced from Armitage, 1993 and Armitage, 1986).**

| Factors | Comments | Importance |
|---|---|---|
| **1. Beginning production** | | |
| Sowing time | The later the sowing and higher temperatures, the more stress on plants in the retail shelf. Late sowings should be planted in larger containers | 3 |
| Container volume | Should be as large as economically possible – helps overcome infrequent watering at retail | 5 |
| Medium | If the mix is well-drained and well-aerated, this is of little importance. Research showed though that adding 10% soil helped shelf-life | 2 |
| Hydrogels | May be effective but research results contradictory | 3 |
| **2. During production period** | | |
| Growth regulators | If grown in warm conditions without growth regulators, plants will be leggy and decline rapidly | 4 |
| **3.Toning practices (acclimatization)** | | |
| Temperature | Reduce by 3 to 5°C when flower bud is visible | 4 |
| Fertility | Reduce fertility concentration by 50% when flower bud is visible | 5 |
| Water | Reduce watering frequency by 50% when flower bud is visible | 5 |
| **4. Out the door** | | |
| | Ensure all dead leaves and flowers are removed and the medium is moist | 5 |

**Table 2. Dispatch and transportation factors that influence bedding plant shelf-life (5 = very important; 1 = little importance) (reproduced from Armitage, 1993).**

| Factors | Comments | Importance |
|---|---|---|
| **1. Dispatch area** | | |
| No petrol or diesel engines | Engines emit large amounts of ethylene – use electrical / battery operated machinery | 5 |
| Keep cool | Cool temperatures reduce sensitivity to ethylene | 3 |
| Keep well-ventilated | Air movement and ventilation will reduce the risk of ethylene build up | 4 |
| **2. In the truck** | | |
| Handle plants gently | Rough handling breaks stems, leaves and flowers and promotes ethylene release | 4 |
| Keep truck cool (12-16°C) | Cooling reduces transpiration, respiration and the effects of ethylene. If a non-refrigerated truck is used then travel in evening / early morning when coolest | 5 |

*Studies not specific to bedding*

*Transport*

Research investigating problems with the transport of pot-plants (Høyer, 1997a) indicated that recorded temperatures in the wagon could vary significantly compared to the set-point value. Temperatures were monitored during 66 delivery trips in 2 trucks which were transporting potted plants. Compared with the thermostat set point of 16ºC, the mean delivery trip temperatures varied between 11.3 and 21.6ºC with up to 3ºC differences within the body of a truck at any one time. The temperature in the body of one of the trucks was found to be strongly influenced by the time of year. The data collected suggested that air circulation was poor and under these conditions water may condense on plants. Høyer (1997a) concluded that the lack of temperature management in trucks would reduce the post-production life of plants, but without any evidence of direct physical damage to the plants. Improved air circulation appeared to help alleviate the problem and it was concluded that warm air must be supplied from the bottom of the body of the truck and cooler air from the top.

Ventilation is also critical in determining exposure to ethylene. Again Høyer's work (1989 and 1995) covering 70 deliveries suggested that the build-up of ethylene during pot-plant transport appeared to be dependent on (1) adequate ventilation, (2) the rate of ethylene production by the load, (3) ethylene production from the material of which the walls were made, and (4) residual ethylene adsorbed onto the truck lining from previous loads and high-ethylene-producing crops. Two trucks were monitored and in one truck, 0.05 $\mu l\ l^{-1}$ (0.05 ppm) ethylene was reached occasionally, while in the other this level was exceeded on 12 occasions for more than 24 hours. Interestingly, damage induced on pot-plants during transport did not cause complaints from wholesalers. There is no comment on what consumers thought!

Simulated transport studies on pot plants have shown that extended storage periods and higher temperatures have caused increased bud drop (Al-Saqri *et al.*, 2003), bud deformation and longer internodes (Sterling and Molenaar, 1986) and shorter flower and plant longevity (Hartley, *et al.* 1995; Leonard *et al.*, 1995). Borch *et al.,* (1996) carried out studies in an attempt to simulate transport conditions imposed on potted rose. The main causes of reduced postharvest longevity were wilted flowers, infection by *Botrytis* and an increased number of yellow buds. The authors found that when plants were assessed 18 days after treatment there were no differences in the percentage wilted flowers for all plants subjected to 0-2 days simulated transport, but there were increases in some cultivars after 4 days simulated transport. The degree of wilting was also dependent on the origin of the plants, and was generally less severe in summer than in winter. Other studies by this group showed large effects between different cultivars of roses, for example, flowers on *Rosa* cv. Elegant Parade were badly damaged by simulated transport (e.g. 4 days), whereas those in

*R.* cv. Dreaming Parade were not. Indeed, some un-opened buds could develop normally in this cultivar as long as the transport period was not excessive (Høyer, *et al.*, 1996). Work by Nell and Noordegraaf, (1992), however, showed that flowering potential in potted rose could be inhibited by simulated transport treatments, but the effects were minimised by exposing the crop to higher light levels during the post-production period. The developmental stage of the rose crop at the time of transport appears to affect the number and quality of flowers produced subsequently (Williams *et al.*, 1995).

Early work investigating transport simulation in poinsettia showed shelf-life reduced by approximately 2 weeks compared to plants that were moved directly from growing to household conditions (van Dijk and Barendse, 1991). Treatments, however, included storage in darkness for 7 days, which is probably extreme by bedding plant standards.

*Ethylene*

The effects of ethylene on plant development are well-documented (e.g. Woltering, 1987; Willumsen and Fjeld, 1995; Høyer, 1996). Symptoms of damage include premature dropping of foliage and flowers or premature flower death (Smith 2001). Flower petals become translucent, some plants develop adventitious stem roots, and petioles may twist (epinasty). Sources of ethylene include; exhaust from cars, trucks and non-electric forklifts; pollutants such as cigarette smoke; plants and flowers that are under stress; fungi such as *Botrytis* and some bacteria; incomplete combustion and / or poorly ventilated heaters located in enclosed greenhouses; and from fruits and vegetables. Generally, reproductive tissues produce more ethylene than vegetative parts. Interestingly, buds themselves are a source of ethylene but also a source of auxins, which promote and inhibit bud abscission, respectively (van Meeteren and van Gelder, 1995). Often the higher the temperature, the less ethylene it takes to induce plant disorders.

Previous studies involving ethylene and transportation have concentrated on cut flowers and pot-plants. Woltering evaluated responses in various foliage and flowering potted plants back in 1986. Plants were exposed to 0 to 15 ppm ethylene for 24 or 72 hours at 20°C darkness. Toxicity symptoms on foliage plants were characterised by abscission and yellowing of leaves. Flowering pot-plants showed abscission of flowers, flower buds or of whole inflorescences. In general, abscission of leaves was only observed when plants were exposed to ethylene for 72 hours while abscission of flowers and flower buds appeared after 24 hours of ethylene treatment. Woltering (1986) could divide the species under test into classes based on ethylene sensitivity.

Post-production longevity and sensitivity to short-term ethylene exposure has been studied in minature roses (*Rosa hybrida*). Twelve different cultivars were treated with a continuous flow of 1 ppm ethylene at 20ºC for 24 hours, when plants were at marketable stage (3-5 open flowers) (Leonard *et al*., 2005). The magnitude of ethylene injury, the time before injury was evident and the plant part affected were found to be cultivar-dependent. For most cultivars, it took several days before the effects of ethylene were apparent, although sometimes injury was noticeable after 24 hours. Short lasting cultivars were consistently found to be sensitive to ethylene, while most, but not all, long lasting cultivars were tolerant. In a study by Muller *et al.*, (2000) rose plants subjected to simulated transportation stress, had reduced shelf-life (In *R* cv. Bronze from 7 to 6 days and in *R*. cv. Vanilla from 23 to 17 days). In *R*. cv. Bronze, the stress resulted in a modest increase in ethylene production, but in Vanilla, it had no effect on the low ethylene production by flowers. Nevertheless, pre-treatment with the ethylene action inhibitor 1-methylcyclopropene (1-MCP) before transport simulation improved display life of both cultivars.

Higher temperatures have been shown to exacerbate the effects of ethylene, with quicker leaf drop noted in *Radermachera sinica* at 15ºC compared to 10ºC (Labouriau and Høyer, 2001). One paper studying *Capsicum* transplants (Kays *et al.*, 1976) also suggested that higher $CO_2$ levels could increase ethylene release from the crop. Presumably $CO_2$ will increase in most crops when they are enclosed during transit and ventilation is poor. Similarly, other studies suggest temporary water stress and wilting can be a precursor to ethylene evolution from the tissues (Mayak and Faragher, 1986).

Some species may be very sensitive to ethylene. *Hibiscus rosa-sinensis* had extensive abscission of flower buds after 24 hours of exposure to 0.05 ppm. In addition to the ethylene response, extensive bud drop was caused by darkness or low light levels (Høyer, 1997b).

A number of chemical, anti-ethylene products have been used in the protection of cut flower and pot-plant crops. Particularly, the use of silver thiosulphate (STS) to offset ethylene induction has been used in a wide range of crop types (e.g. Moe and Smith-Eriksen, 1986; Høyer, 1986, 1998a; Custódia *et al.*, 2001). Leaf abscission caused by ethylene can be reduced by STS (Høyer, 1998a). Treatment with 4.05 mM STS, 1 or 11 days before ethylene exposure, considerably reduced the ethylene induced abscission, but with little noted effect of the treatment when applied 21 days before ethylene exposure.

Of bedding species, *Impatiens* has been identified as relatively susceptible to ethylene damage. Exposure to exogenous ethylene caused corolla abscission in New Guinea impatiens (*Impatiens* x *hawkeri* cv. Sunfire), with 80-100% abscission resulting even after only 4 hours exposure to 1 ppm ethylene. Simulated shipping of untreated control plants caused approximately 65% abscission. (Dostal *et. al.,* 1991). Pre-treating plants with STS or (aminooxy)acetic acid before simulated shipping gave positive results, with either substance reducing abscission to approximately 20% when applied at 1.0 mM. When pre-treated plants were exposed to set concentrations of ethylene (1 ppm) however, (rather than simulated transport *per se*), responses were markedly different and only the STS reduced corolla abscission. This suggests that the (aminooxy)acetic acid may be involved in minimising corolla abscission during transport, but this may not relate to an anti-ethylene response. Variations in results between simulated transport experiments and those where plants are simply exposed to an ethylene concentration, may again suggest (see Høyer, 1997b) that other factors contribute to loss of quality, or that there are interactions between ethylene and some of these other factors (light, humidity, temperature, pathogen presence etc.).

*Temperature and humidity*

In an attempt to determine the best packing sleeve for potted cyclamen, Geoffroy and Vial, (2004) evaluated changes in environmental condition during transit and distribution. At the time of conditioning, temperature was 19ºC and relative humidity (r.h.) 80%. During the waiting phase before, and during transport itself, r.h. was 100% and the temperature decreased to 16ºC. The authors found that the duration of exposure to 100% r.h. varied with the type of film used (pre-stretched, classical, perforated or net).

Work on *Kalanchoe blossfeldiana* showed that post-production quality was significantly affected by flowering stage and transport temperature during transit (YounJung, *et al.*, 2003; Leonard and Nell, 2000). Plants transported at 18ºC had shorter longevity, but increased flowering rate, than those at 12ºC. Plants that had low flower rates at time of transportation (5%), had greater longevity than those that were already well into bloom (50% flower cover).

Inappropriate humidity during production has been linked with quality problems (Hendriks, 2001), and it must be assumed that this factor during transit also may influence shelf-life, especially if the crop is exposed to too high or too low a humidity for a prolonged duration. Responses again may be species specific, for example high humidity during production caused loss of quality in cut roses, but no affect in *Chrysanthemum*, *Euphorbia* (poinsettia) or *Begonia* (Mortensen, 1998), and even appeared to improve shelf-life in *Argyranthemum* (Høyer, 1998b). In contrast to Mortensen (1998), Fjeld (1986) found high humidity (90%) during production of *Begonia* induced stem elongation and loss of quality. It is recognised that high humidity will induce the spread the *Botrytis* and other pathogens, especially if plants have been stressed excessively or physically damaged, but direct effects of high humidity associated with transit are not well-documented. Problems may not be restricted to high humidity; low humidity (e.g. < 80% r.h.) can result in bud drop in some flowering pot-plants (Song and Lee, 1994).

*Light*

Unlike foliage pot plants where light acclimatization is important, it is generally considered that high light levels should be maintained over bedding plants during production and on the retail bench (Armitage, 1993; Fjeld, 1986). Interestingly, work on pot rose showed that bud drop was increased after transport when plants were placed in a simulated retail environment with only 1 W $m^{-2}$ light provided. The authors concluded that bud drop can be minimized by high post-production irradiance levels following transport (Nell and Noordegraaf, 1992).

A lack of light during shipping was attributed to leaf drop in *Ficus*, but the experimental periods examined (7 and 14 days darkness, Mulderij, 1991.) were in excess of what would be considered appropriate for bedding. Nell and Reid (2000), suggest that 2-3 days is the maximum storage / transport time for a range of bedding, possibly because lack of light and ethylene become significant factors after this. This is broadly in line with specific crop information provided by Armitage (1993), where, for example, leaf chlorosis can occur after 48 darkness (*Pelargonium*), or young flower buds abscise after 36 hours (*Impatiens*).

*Nutrition and irrigation*

There appears to be a consensus that high fertiliser feeds (particularly nitrogen, Druege, 2001; ter Hell and Hendiks, 1995) during production of both flowering and foliage ornamentals can reduce shelf-life and encourage physiological disorders (Nell and Barrett, 1990). Armitage (1993), however, is clear to point out that this should not be interpreted as giving no feed during the latter stages of production. Work on *Petunia*, suggested that flower quality at retail was enhanced when the normal fertiliser rate of 200 ppm was reduced to 100 ppm at the first flower bud stage (Armitage, 1986). Information on nutritional responses and transportation in other bedding species appears limited. Armitage (1993) suggests that nutrition levels can be reduced in line with lower irrigation frequencies during the last week or so of production (see toning practices, Table 1).

Due to problems associated with drought, many growers may wish to thoroughly irrigate the crop prior to transport, however, work from PC 200 (Edmondson and Parsons, 2005) suggested that irrigation prior to dispatch did not necessarily maximise quality. This aspect is covered in the current project.

*Vibration*

The extent to which vibration during transport causes injury appears to vary with crop, and packing materials employed. Bulle *et al.*, (2000) stated that vibration caused severe damage to leaves and open flowers of pot-plants with greater than 40% of the open flowers of *Achimenes*, *Impatiens* and *Streptocarpus* being damaged after 2 days treatment. They found no long term physiological effect though, and concluded that shelf-life appeared to be more influenced by a dark period than by vibration. In contrast, in *Kalanchoe*, YounJung, *et al.*, (2003) found little direct damage from vibration in transit.

*Concluding points*

The literature suggests that a range of environmental variables can act independently, or in combination to affect ornamental plant quality during transit. One of the key elements of this project was to determine which stress factors were commonplace for bedding plants during distribution within UK, and / or whether a number of factors could come together and result in a crop rejection. Therefore, it was important to both combine information collected from industry and from controlled scenarios to determine the likelihood of such factors being a problem in reality.

## Materials and Methods

Plant material was either monitored *in situ* (on wagons, nurseries hubs etc.) (Year 1), bought in from commercial sources (Year 2) or where a degree of control was required on crop husbandry, grown at the Glasshouse Unit (School of Biological Sciences – University of Reading) (Year 3).

### Growing and storage conditions

Under the controlled experiments of Years 2 and 3, plants were grown or maintained in glasshouses and polythene tunnels before (and after) being exposed to simulated transport conditions (storage). Transport conditions (the vehicle's wagon!) were simulated using environmentally controlled cabinets (Saxcil Cabinets Ltd., Cheshire). These provided temperature regulation between -10 to 40ºC +/- 0.5ºC. and had dimensions of 100 cm x 120 cm x 150 cm, which allowed 45 trays to be placed within at the one time. In an attempt to scale up to conditions more realistic of a lorry wagon, however, three 'walk-in' chambers were also utilized in some experiments. These were 200 cm x 210 cm x 280 cm and could house two Danish trolleys each (approx. 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.

### Environmental monitoring

Temperature and humidity data was collected via probes (TinyTag, Extra-3580, Gemini Data Loggers, Chichester, UK). These were used both for monitoring conditions in industry and for recording conditions in the environmental cabinets. Probes were placed onto a pack of bedding plants, which was usually located in the middle of a 'Danish trolley' or in the centre of the environmental cabinet. The probes were set to record data every 10-15 minutes and could be programmed for a duration of 55 days. On a number of commercial runs, the temperature of the growing medium was recorded in parallel with air temperature at the crop canopy level.

In commercial situations growers / drivers were requested to provide supplementary information on time of loading, departure, arrival, no of intervening stops, weather conditions and type of crop and lorry (wagon). Data from these questionnaires were then used to interpret alterations in the temperature and humidity data sets, derived from the probes.

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.

**Plant husbandry**

In Years 2 and 3 bedding plants were purchased from commercial nurseries or grown-on at Reading, respectively. The experimental unit was a 6-cell-pack of plants. When purchased as a finished product, crops were delivered earlier than normal (e.g. before bud colour was showing) and plants allowed to become 'acclimatized' at Reading before being placed in simulated transport (storage) treatments (this reduced the likelihood of any residual effect associated with the transportation to Reading itself). Plants purchased or grown-on at Reading (see later) were housed in a conventional glasshouse, maintained at a temperature range of 18-28ºC depending on time of year (heated winter and well-vented summer). After exposure to storage treatments, 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. Although temperatures could vary within the polytunnel over the assessment periods, the most extreme temperatures actually recorded were 8ºC for 3 hours (Polyanthus crop in October 2006) and 35ºC for 2 hours (Impatiens crop in June 2008).

Species selected tended to reflect the most popular bedding species at various times of the growing season (Pansy, Petunia, Impatiens etc.) or where particular problems had been identified by growers (e.g. *Botrytis* occurrence on Polyanthus). Details of cultivars are included in the descriptions of the individual experiments.

**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. The plant health score was modified in Year 3 to distinguish injury to leaves and injury to flowers separately.

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. There was a minimum of five assessors for each experiment.

**Statistical methods**

Relatively simple data sets were generally analysed by analysis of variance. In most experiments a control group of plants was included (e.g. placed in a polytunnel without any additional treatments), so data sets tend to be presented as a single factor analysis, to allow direct comparisons to the control. Additionally, however, controls were often excluded from the data sets and multi-factorial analyses attempted (e.g. temperature x humidity etc.) to verify any overall significant effects attributed to key factors. Data from these, however are only discussed when they contribute additional information to that of the single factor analyses.

In Year 2 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 to the experimental procedures. In Year 3, however, it was important to clarify the original treatment effects (before storage) and how these changed during storage so data is presented for both before and after, with no co-variance used.

Data are usually 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.

**Experiment 1 (Year 1)**

**Monitoring environmental conditions on nurseries, commercial wagons and distribution points (hubs)**

From a period between April 2005 and July 2006, approximately 25 separate transport movements (transit runs or runs) were monitored and information collected on crop temperatures (temp.), relative humidity (r.h.) and logistics of the movement (nursery location, destination, timings etc). These runs would sometimes include non-bedding plant material, such as nursery stock items, in mixed loads.

**Experiment 2 (Year 2)**

**Temperature and duration of transport conditions using autumn and spring bedding**

Data from Experiment 1 was used to set up the conditions for simulated transport (storage) conditions using the cabinets at Reading. The objective of Experiment 2 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 12°C for 24 hours
**12C 48h**: Plants kept at 12°C for 48 hours
**22C 24h**: Plants kept at 22°C for 24 hours
**22C 48h**: Plants kept at 22°C for 48 hours
**Wet 12C 24h**: Plants kept at 12°C 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 2$^{nd}$ and 6$^{th}$ 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 23$^{rd}$ and 26$^{th}$ April 2007. There were 12 replicate trays per species per treatment.

**Experiment 3 (Year 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 2007 (temperature 29$^{o}$C and 1,250 μmol $s^{-1}$ $m^{-2}$ {65,000 lux}).

Full storage treatments were;

**Poly Con:** Polytunnel throughout
**Poly Dry:** Polytunnel throughout but not watered for 24 hours beforehand
**Poly WetL:** Polytunnel throughout but leaves sprayed with water 3 times a day
**35C Con:** 35°C in the dark
**35C Dry:** 35°C in the dark but not watered for 24 hours beforehand
**35C WetL:** 35°C in the dark but leaves sprayed with water 3 times a day
**12C Con:** 12°C in the dark
**12C Dry:** 12°C in the dark but not watered for 24 hours beforehand
**12C WetL:** 12°C in the dark but leaves spayed with water 3 times a day
**8C Con:** 8°C in the dark
**8C Dry:** 8°C in the dark but not watered for 24 hours beforehand
**8C WetL:** 8°C in the dark but leaves sprayed with water 3 times a day

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

**Experiment 4 (Year 2)**

**Controlled temperature and light combinations**

This was similar to Experiment 3, 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:

**15L-15L** = Control: 15°C in the light moved to 15°C in the light

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

**Experiment 5 (Year 2)**

**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:

**Control:** Maintained in polytunnel
**12C H 24h:** 12ºC 100% r.h. for 24 hours
**12C H 48h:** 12ºC 100% r.h. for 48 hours
**12C L 24h:** 12ºC 50-65% r.h. for 24 hours

**12C L 48h:** 12ºC 50-65% r.h. for 48 hours
**22C H 24h:** 22ºC 70-80% r.h. for 24 hours
**22C H 48h:** 22ºC 70-80% r.h. for 48 hours
**22C L 24h:** 22ºC 10-15% r.h. for 24 hours
**22C L 48h:** 22ºC 10-15% r.h. for 48 hours

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 placed over wet cloths.

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

**Experiment 6 (Year 2)**

**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 12ºC and one at 22ºC. 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}.

**12C Open:** 12ºC open on trolleys
**12C Boxed:** 12ºC in boxes
**12C Polywrap:** 12ºC on trolleys covered with polythene wrapping
**22C Open:** 22ºC open on trolleys
**22C Boxed:** 22ºC in boxes
**22C Polywrap:** 22ºC on trolleys covered with polythene wrapping.

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

**Experiment 7 (Year 3)**

**Does crop pre-treatment (toning) help retain quality during transportation?**

The objective of this experiment was to determine if cultural techniques during the production phase could help improve plant robustness prior to transportation, thereby reducing the likelihood of injury or loss of quality.

Three main season bedding plant types were used in this experiment: - Petunia cv. Frenzy Blue; Impatiens cv. F1 Expo White and Pelargonium cv. Bulls Eye Scarlet. Plants were bought in at the plug stage from commercial nurseries and potted into 6-cell polystyrene trays using a 70% Peat:30% Cambark mix, with 3 $g^{-1}$ Osmocote-Exact-Mini pellets incorporated (3-4 month formulation 16:8:11:2, N,P,K,MgO with trace elements, Scotts UK Professional, Bramford Suffolk). Plugs were potted on the following dates; Pelargonium 23 April, Petunia 7 May and Impatiens 10 May, 2008 and plants placed in a glasshouse maintained at temperatures regimes based on venting at 17ºC during the day and heating to 14ºC when required. Plants were left to establish for 1 week before treatments were imposed, at which point they were graded and divided into two positional blocks within the glasshouses (6 trays per block).

Plants were divided into the following treatments:

**Polythene tunnel control (Poly)** - Plants maintained in glasshouse and then placed in a polythene tunnel during the period other treatments were exposed to a simulated transport (storage) treatment.

**Control (Con) –** Plants maintained in glasshouse and then exposed to a simulated transport (storage) treatment.

**Cool grown (Cool) –** Plants moved from the main glasshouse one week after potting to another glasshouse with a forced ventilation system. This kept plants approximately 2ºC cooler than those in the main glasshouse.

**Calcium chloride (CaCl) –** This was one of two treatments aimed at increasing the electrical conductivity of the medium, with the objective of moderately stressing plants to both improve their growth habit and increase their tolerance to subsequent stress (acclimation). Calcium chloride was applied at 2.8 g $l^{-1}$ (equivalent to 3mS $cm^{-1}$ electrical conductivity) on three separate occasions (approximately 2 week intervals) during the production of the crop.

**Potassium chloride (KCl) –** This was the other treatment aimed at increasing the electrical conductivity of the medium, with the objective of moderately stressing plants to both improve their growth habit and increase their tolerance to subsequent stress (acclimation). Potassium chloride was applied at 1.6 g $l^{-1}$ (equivalent to 3mS $cm^{-1}$ electrical conductivity) on three separate occasions (approximately 2 week intervals) during the production of the crop. (Potassium chloride is more likely to be used by growers to increase electrical conductivity than calcium chloride, but will also supply potassium which as a major plant element may influence growth directly).

**Potassium phosphite ($PO_3$) –** $KPO_3$ was included as it is thought to be able to allow phosphorus into the plant tissues very efficiently and that phosphorus in various forms has been cited as influencing shoot extension (Broschat, 2006, Chantry, 2007). It was considered that this product may encourage a more compact plant habit. Again, with the formulation used (‘Horti-phyte’, Hortifeeds Ltd. Lincoln, UK) a potential drawback was that N and K would also be introduced in addition to P (4:30:8, N:P:K ratio).

**Growth regulator (GR)**. - This was applied either as a one-off application 5 days before simulated transport **(GRx1)**, or as an additional application two **(GRx2)** and four weeks preceding this **(GRx3)**. Bonzi (4 g $l^{-1}$ [0.39% w/w] paclobutrazol, Syngenta Crop Protection, Inc. Greenboro, North Carolina, USA) was applied as a drench at a 1.25ml $l^{-1}$ rate for Pelargonium and Impatiens, whereas B-Nine (daminozide 85% w/w, Certis, Amesbury, Wiltshire) was applied to Petunia at 3 g $l^{-1}$.

**Brushed (Br)** – Plants were brushed carefully with a soft-wired dustpan brush daily. The brush was passed over the crop canopy of each tray in the treatment, 10 times on each occasion.

**Low watering regime (LW)** – Plants were given 50% less water than controls during the production phase, but well-watered before being introduced to the simulated transport storage.

**High watering regime (HW)** - Plants were given twice as much water (200%) as the controls during the production phase. This was considered a deleterious treatment with the objective to determine how poor husbandry may interact with a subsequent long storage period. It was also anticipated it may encourage disease that would become more-fully expressed during storage.

Chemicals were applied in a similar manner throughout, with application via a watering can and rose being used. This allowed solutions to penetrate the growing media and to leave residues on the crop foliage itself, thus facilitating uptake via roots and shoots.

Plants were maintained to keep the crop on the 'dry side' where possible and watered once every one to two days on average. Application rates on each occasion were approximately 500 ml water per tray via a watering can and rose. Plants in the Low watering regime were given half the normal volume, and those on the High watering twice the normal volume, but at the same frequency as the other treatments. When a chemical treatment was being applied as a drench, this was taken account of when watering the rest of the crop; other treatments would receive the equivalent volume of water. Trays were weighed weekly (at approx 2 hours after watering) and typical weights were 750 g to 900 g per tray. In contrast plants in the Low watering regime were kept as low as between 350 g to 500 g depending on stage of development, and between  850 g and 1260 g in the High watering treatment.

One of the worse treatments from the previous years results was chosen to simulate one of the more extreme transport storage conditions encountered. This was storing trays for 48 hours at 20ºC and 95% relative humidity. Each species was treated to storage separately, with treatments being divided between two Saxcil cabinets. Plants were assessed for quality parameters as before with the exception that injury scores were sub-divided between leaves and flowers to provide more information on loss of quality. Quality was measured 24 hours before and 3 and 24 hours after storage. After storage, plants were placed in a polythene tunnel for assessing (where they joined the Poly treatment plants which had been given no storage treatment). Data is presented as mean score showing data for 24 hours before and 3 hours after storage – data for 24 hours after showed little variation in treatment trends and has been omitted).

## Results

### Experiment 1 (Year 1)

### Monitoring environmental conditions on nurseries, commercial wagons and distribution points (hubs)

### Characteristics of the 'average' run

One of the first objectives of the project was to understand the temperature and humidity changes that crops were exposed to during transportation. No two runs were identical. However, generic information could be gained by comparing a number of different data sets. For example, it was clear that the crop would often be exposed to a sharp temperature decline when it was loaded. This was either due to the wagon being naturally cooler (shaded, damp etc) or it had been pre-chilled by the lorry's refrigeration unit. In addition, some of the downward temperature trends may be related to watering the crop in dispatch, just prior to loading. Often (but not exclusively), the temperature in the wagon itself was relatively stable, with very few sharp transitions, although 'troughs and peaks' could occur when doors were opened. A typical (or 'average') data set is depicted in Figures 1 (temperature) and 2 (relative humidity, r.h.). In the majority of cases the reduction in temperature when the crop is placed in the wagon is matched with a rise of r.h., often to 100%.

For this particular run on 10 May 2006, weather conditions at time of departure were quoted by the driver as overcast and cool (10-14ºC), although it would appear the crop (38 trolleys of *Antirrhinum*) had been kept somewhere warmer than this (21ºC). Once the crop was placed inside the wagon, temperatures were approx 12.5ºC for air and 12ºC for roots during transit. Outside temperatures at arrival, however, were quoted as 21.5ºC, but this did not appear to have influenced those within the wagon. It was not clear in this scenario whether the wagon's refrigeration unit was operating. On arrival, plants were scored for quality and were deemed to be top quality (10 / 10 score) implying no immediate loss of quality during transit.

**Figure 1. Nursery B - Crop (*Antirrhinum*). Air and soil temperature. Articulated rigid-body (refrigeration not stated). Single run to Swindon, Wilts.**

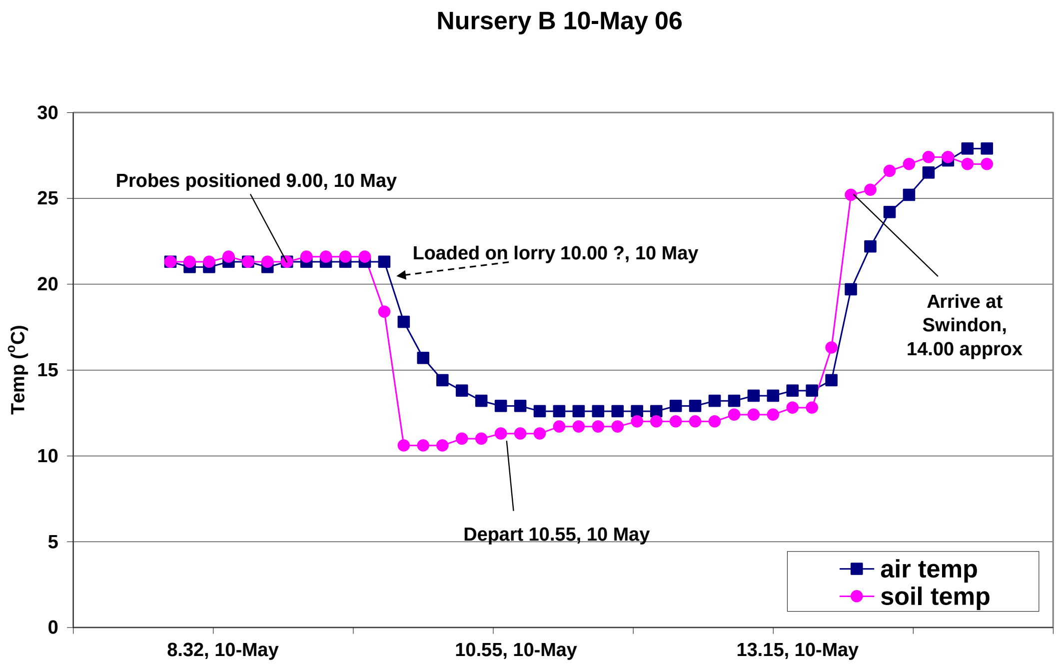
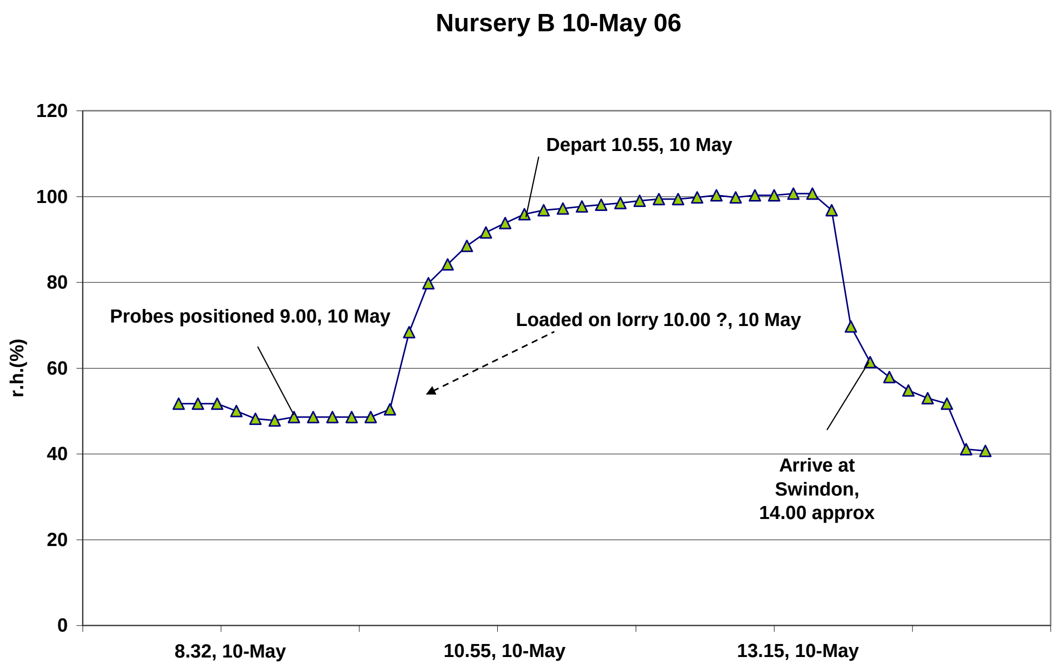



**Figure 2. Nursery B - Crop (*Antirrhinum*). Relative humidity. Articulated rigid-body (refrigeration not stated). Single run to Swindon, Wilts.**



**Stored the night before**

For a number of nurseries it was more convenient to load a lorry the night before departure, so as to allow a quick departure the following morning. Temperatures during this night storage period could be relatively high, or relatively low, depending on time of year, weather conditions and whether the chilling unit was being employed. In some cases the back door of the lorry was left open to help reduce temperature and humidity. The lowest recorded night temperature was approx. 11ºC (Figure 3), with 100% r.h. (Figure 4) and highest was 23ºC with again r.h. reaching 100% (Figure 5). In both these cases a non-refrigerated wagon was used and in the case of the higher temperatures, the wagon doors were left open in an attempt to avoid excessive heat.

**Variability in temperature and humidity during transit**

Lorry type (and in non-refrigerated lorries, weather) had a strong influence over the temperatures the crop experienced during transit. For example, temperatures were often stable when chilling units were used (Figure 6), but less consistent when they were not (Figure 3 and Figure 8). Similarly, r.h. was more uniform (Figure 7) under more stable temperatures and more variable as temperatures oscillated (Figure 9).

Figures 8 and 9 represent one of the most variable data sets recorded. This wagon was non-refrigerated and the crop appeared to be largely influenced by the ambient conditions outside. There was a slow reduction in temperature (reaching 9.2ºC) during the night following loading, then a progressive increase as the lorry proceeded to deliver its load to a number of garden centres. At the final destination, air temperature was 27ºC and soil temperature was 22ºC. Humidity fluctuated during the delivery period, but generally decreased with time and with the removal of the load in batches. One of the biggest drops in r.h related to the delivery at Brocksworth, and this correlated with the lorry doors being open for longer than at other deliveries (45 minutes compared to the more usual 20 minutes). This may also relate to a greater proportion of the crop being removed at this destination (hence, higher temperatures and lower r.h. afterwards).

It is interesting to note that although the data comparisons contrasted strongly between Figures 6 & 7 and those of Figure 8 & 9, the data sets are from the same nursery recorded over the same day. This highlights, the extent to which vehicle type and transport dynamics may vary even within the one company. Indeed, another data set was also recorded from this nursery over the same period (Figures 10 and 11). It is less clear in this run as to whether the crop was artificially chilled, as the temperature decreased more gradually compared to that in Figure 6. (Questionnaires stated that both were lorries with refrigeration units, but the information provided did not verify if and when the refrigeration units were switched on).

**Figure 3. Nursery B - Crop (bedding and roses). Air and soil temperature. 18 tonne, rigid-body with opaque roof (no refrigeration). Multiple run with final destination High Wycombe, Bucks.**

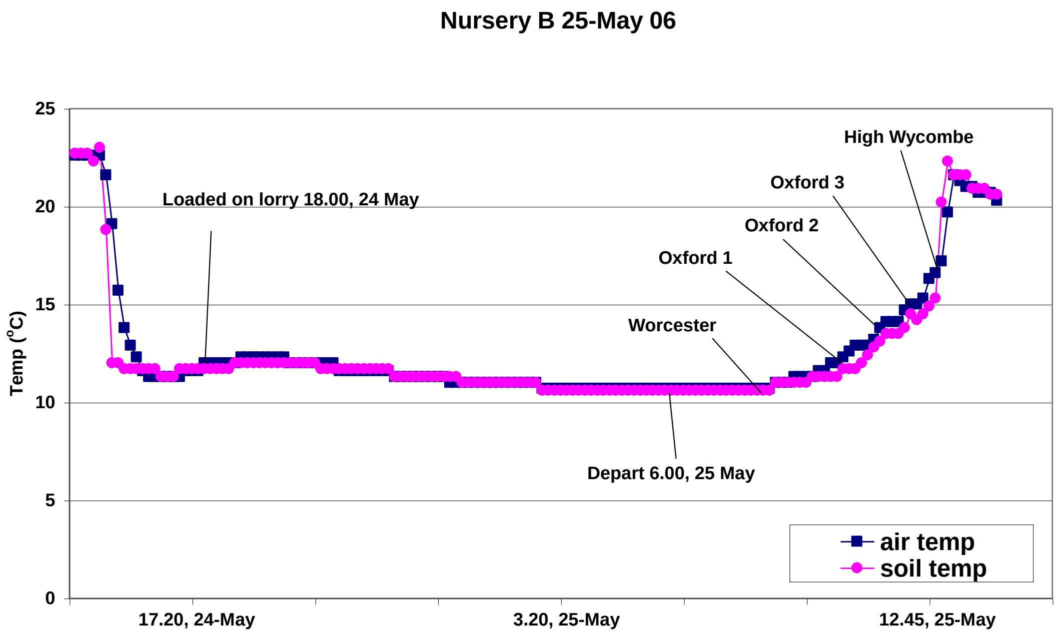
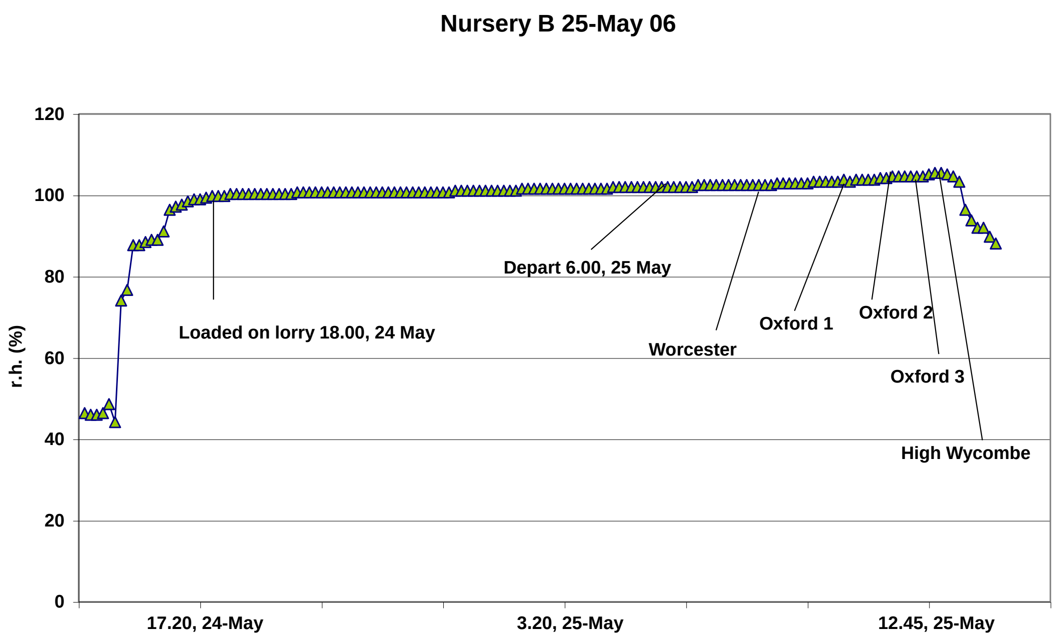
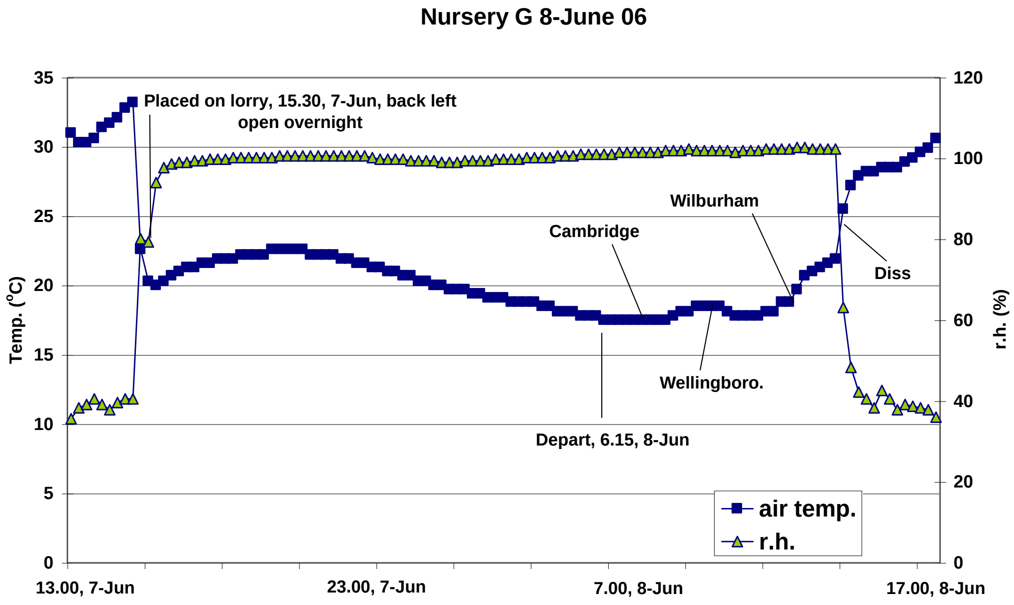



**Figure 4. Nursery B - Crop (bedding and roses). Relative humidity. 18 tonne, rigid-body with opaque roof (no refrigeration). Multiple run with final destination High**




**Wycombe, Bucks.**

**Figure 5. Nursery G - Crop (mixed bedding). Air temperature and relative humidity. 13 tonne, rigid-body and no refrigeration. Multiple run around East Anglia – warm weather.**




Although all the facts cannot be confirmed, these data sets imply that temperature is more variable when there is no artificial chilling, and that crops may be exposed to relatively high temperatures (e.g. 27°C just before Hazelfield – Figure 8), at least during part of their journey.

**Figure 6. Nursery A - Crop (unknown). Air and soil temperature. 18 tonne, rigid-body, refrigerated lorry (refrigeration unit on – not verified). Short, multi-drop run to Wokingham, Berks.**

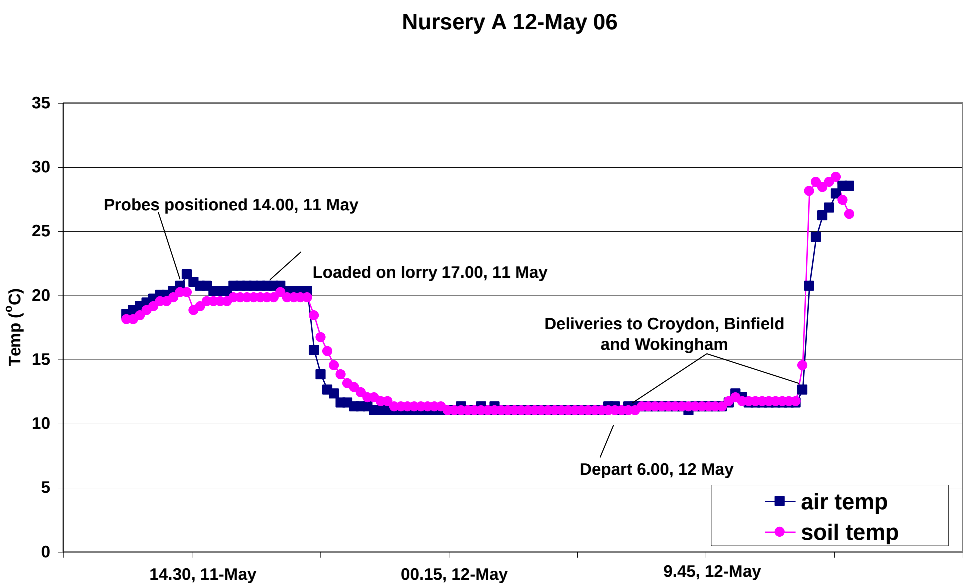


**Figure 7. Nursery A - Crop (unknown). Relative humidity, 18 tonne, rigid-body, refrigerated lorry (refrigeration unit on – not verified). Short, multi-drop run to Wokingham, Berks.**

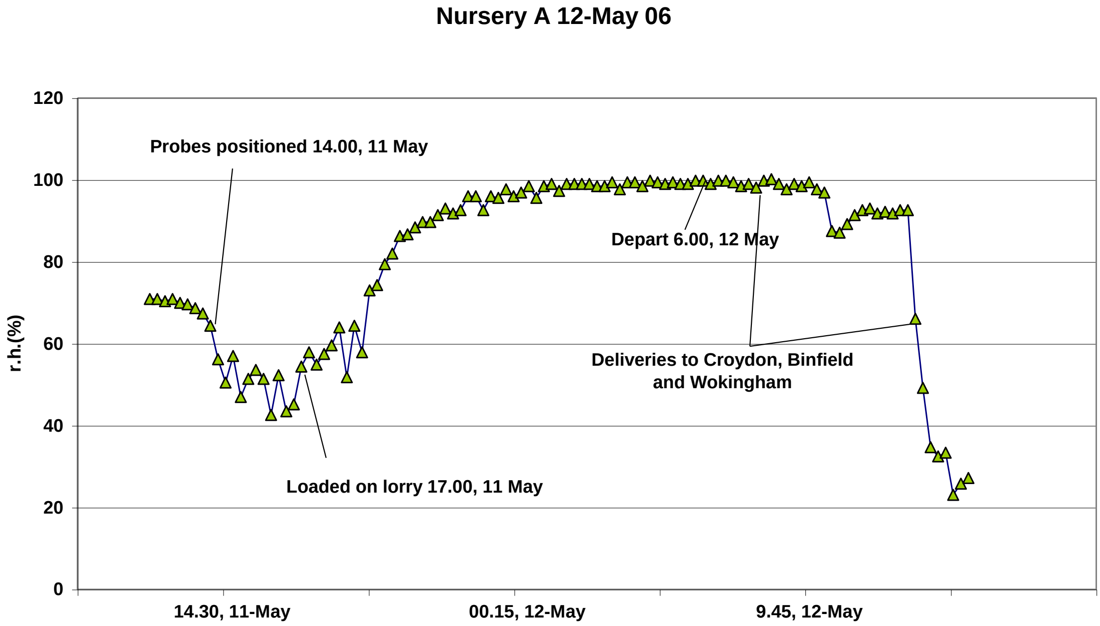



**Figure 8. Nursery A - Crop (unknown) Air and soil temperature. 18 tonne, rigid-body, non-refrigerated lorry. Multi-drop run to Hazelfield (Glos.).**

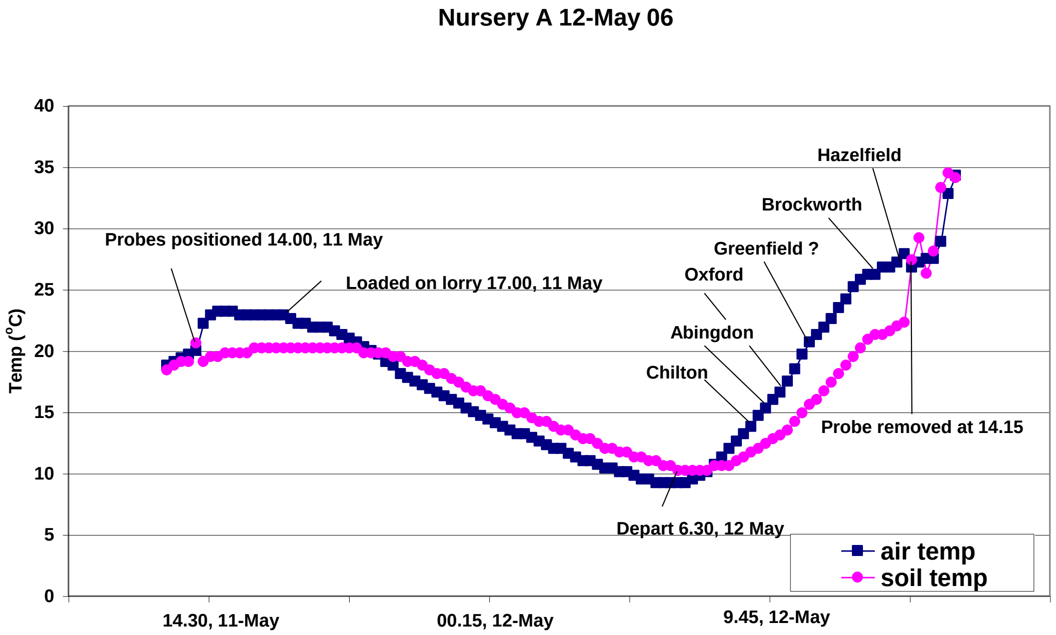


**Figure 9. Nursery A - Crop (Unknown). Relative humidity. 18 tonne, rigid-body, non-refrigerated lorry. Multi-drop run to Hazelfield (Glos.).**

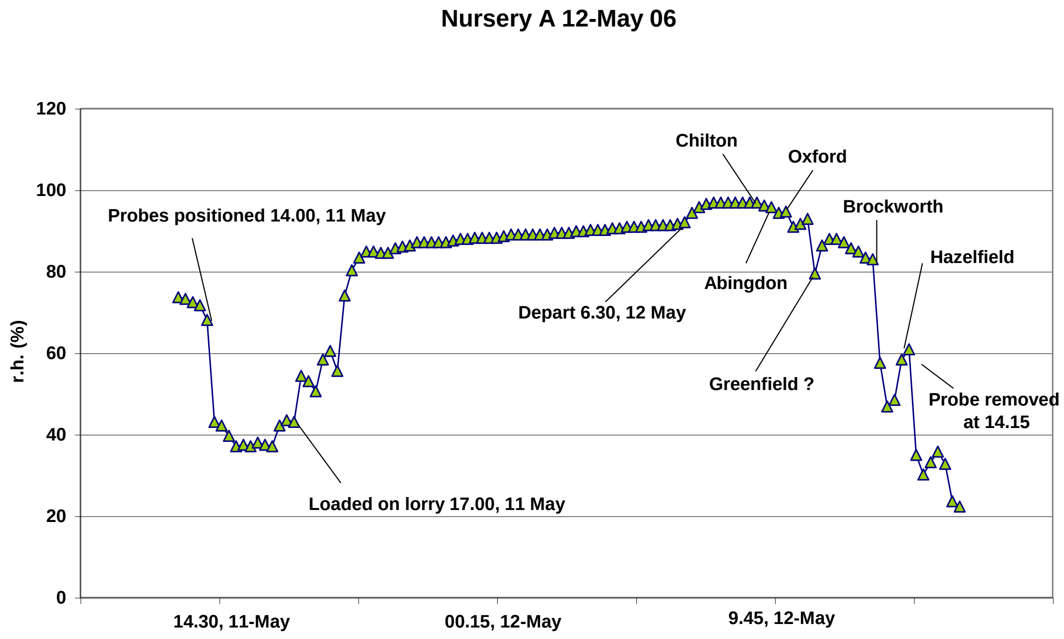



**Figure 10. Nursery A - Crop (unknown) Air and soil temperature. 18 tonne, rigid-body, refrigerated lorry (refrigeration unit on – not verified). Multi-drop run to Brynawel, Wales.**

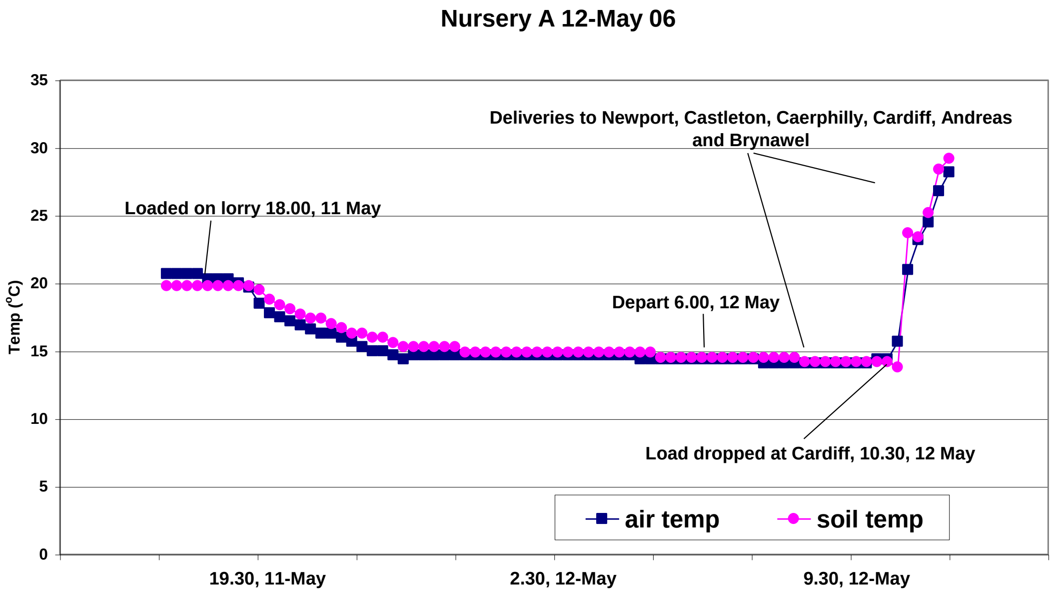
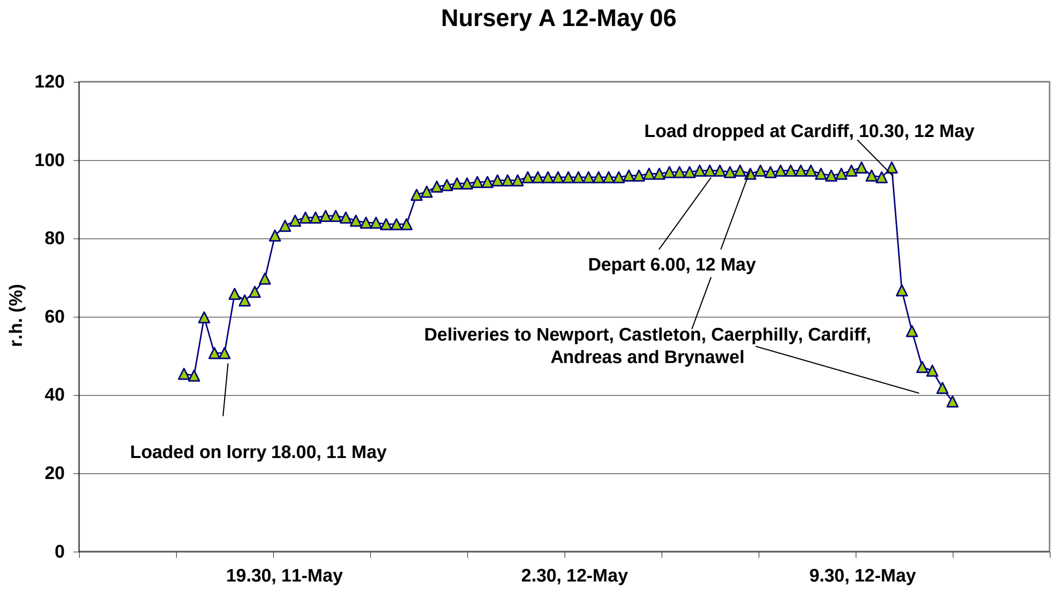


**Figure 11. Nursery A - Crop (unknown). Relative humidity. 18 tonne rigid-body, refrigerated lorry (refrigeration unit on – not verified). Multi-drop run to Brynawel, Wales.**




## Highest and lowest absolute temperatures recorded during transit

The lowest temperature recorded for a crop in the wagon occurred on 21 November 2005, when a temperature of 4.8$^{o}$C was recorded (Figure 12B). Unfortunately, the information from this questionnaire was limited and there was no information on crop type or whether the wagon was temperature controlled. Because the delivery was late in the autumn, it was likely the crop type was hardy, and temperature control was not considered necessary. A previous run, approximately 10 days earlier (Figure 12A) recorded a lowest temperature of 10.2$^{o}$C (in the media) and the variation between the two runs may suggest that a non-temperature controlled wagon was being used for these distribution runs. In both cases there are large temperature and r.h. fluctuations, once the crops have reached their destinations. (e.g. in A from 12.3 to 26.5$^{o}$C and from 95 to 36 % r.h.).

**Figure 12. Nursery D - Crop (unknown) Air and soil temperature and relative humidity. Two separate runs – lorry and crop type unknown. Single destinations unrecorded.**

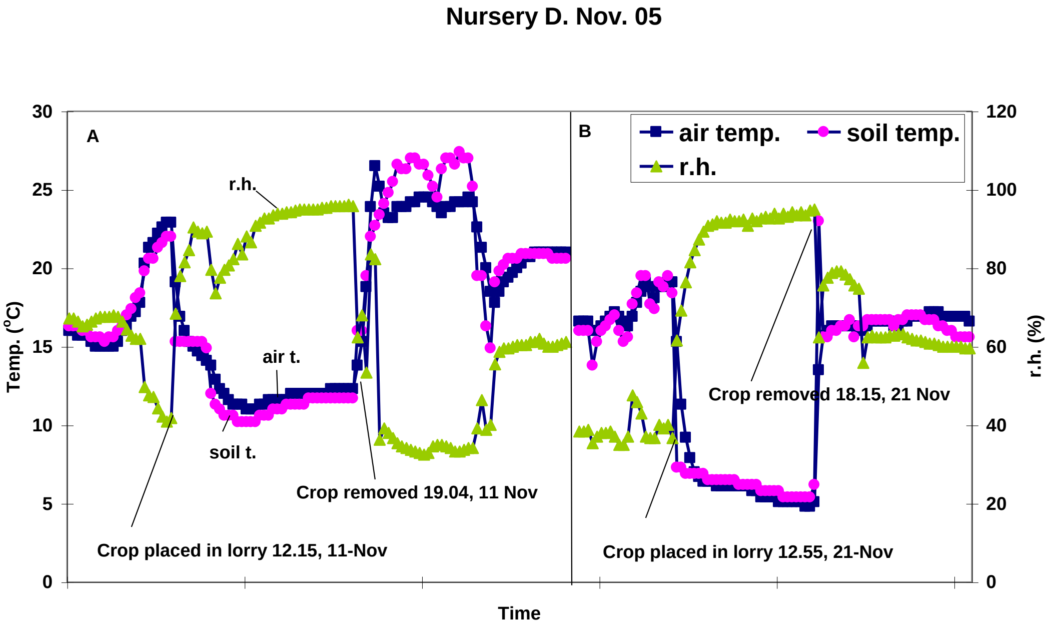



**Figure 13. Nursery D - Crop (unknown) Air and soil temperature. 26 pallet refrigeration lorry but refrigeration unit not running. Single destination to Bradford – weather very hot.**

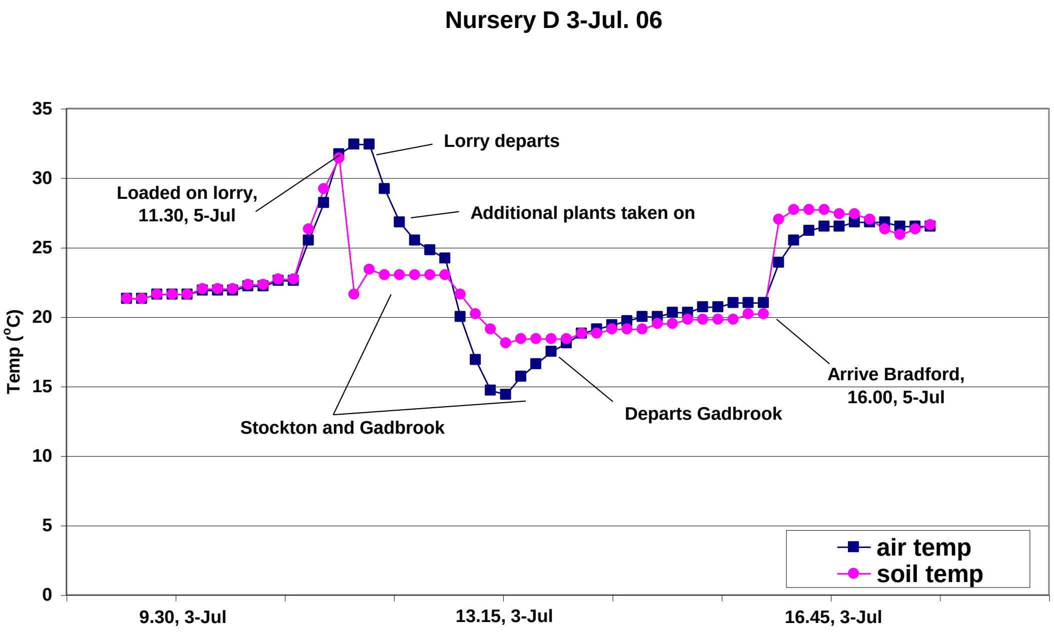
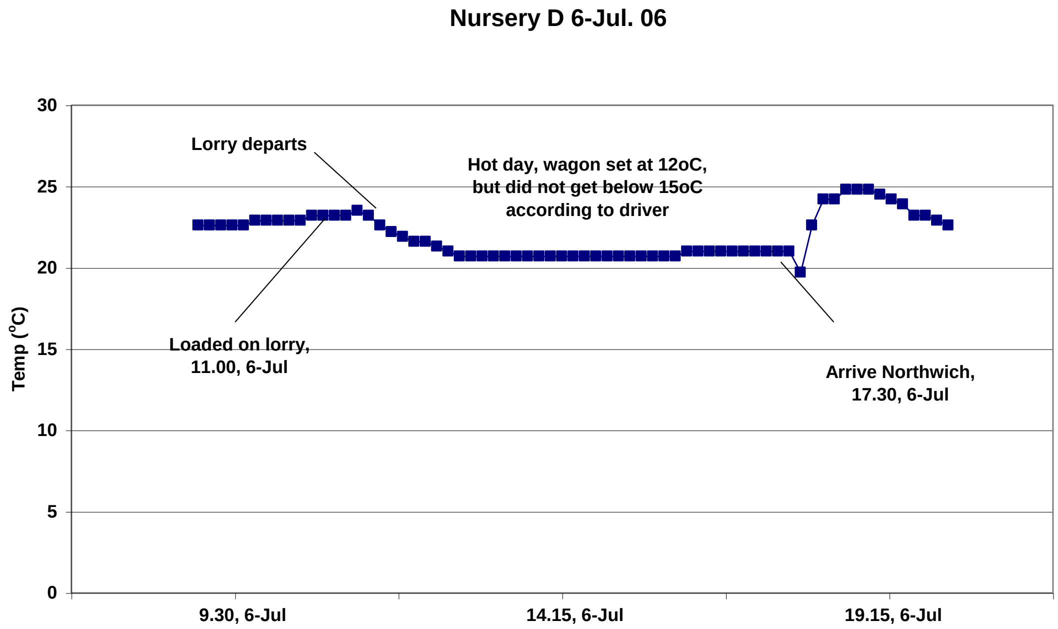


**Figure 14. Nursery D - Crop (unknown). Air temperature. Articulated refrigeration lorry with refrigeration set to 12°C, but where driver claimed that temp was approx 16°C. Single destination to Northwich – weather warm and humid.**




In addition to short periods of warm temperatures (27°C - Figure 8 and 33°C Figure 13), high temperatures in wagons could be recorded for relatively prolonged periods, (e.g. Figure 14), where plants were held at or above 20°C for almost 6 hours. During such periods the crop would be held in the dark and at high humidity (> 95% r.h.). It was also evident it took sometime for crops to lose their heat once placed on the wagon (e.g. Figure 13). The sharp drops in soil temperature (Figure 13) are possibly watering events, but if so these have not lowered canopy temperatures as rapidly as the rootzone.

One interesting point from Figure 14, was that although the driver acknowledged his chilling unit was not reaching the desired temperature of 12°C, he was still over-estimating its chilling capacity (he considered temperatures had reached 15°C, whereas the probe indicated that the lowest was only 20.7°C). This may relate to variations in positions of the two different temperature sensors (probe and cab sensor), but also highlights that cab readings may not be particularly accurate, or may not be representative of the entire load.

## Duration of transport runs

Many of the data sets recorded short duration runs of only a few hours, but it was acknowledged at the start of the project that transport durations of 2-3 days can take place (e.g. from SE England to Northern Ireland). The longest run recorded in the project was approx. 42 hours. An 18 tonne rigid body, refrigerated lorry was used for this run, but the refrigeration unit was not used. The driver stated outdoor temperatures were about 14-15°C during the earlier deliveries on day 1, with an increase to 19-20°C during the latter deliveries of day 1. This may correspond to the slight increase in temperature noticed in the crop after 14.30, but only to 16°C. (Figure 15). Humidity in the crop also dropped around this time (Figure 16), suggesting the doors had been open for a delivery.

The lorry was stationed overnight near Cardigan, before further deliveries the following day. Probe data suggested that the crop was held at approx 15°C and r.h. >95% - for the second night running. Deliveries the following day were associated with marginally lower temperatures 12°C recorded (and 9.0°C outside temperatures reported by the driver) and lower humidities – a possible consequence of the doors being open and the load in the trailer being much reduced (Figures 15 and 16).

**Figure 15. Nursery A - Crop (unknown). Air and soil temperature. 18 tonne rigid-body, refrigerated lorry, but run at ambient. Two day run, with final = Brecon, Powys.**

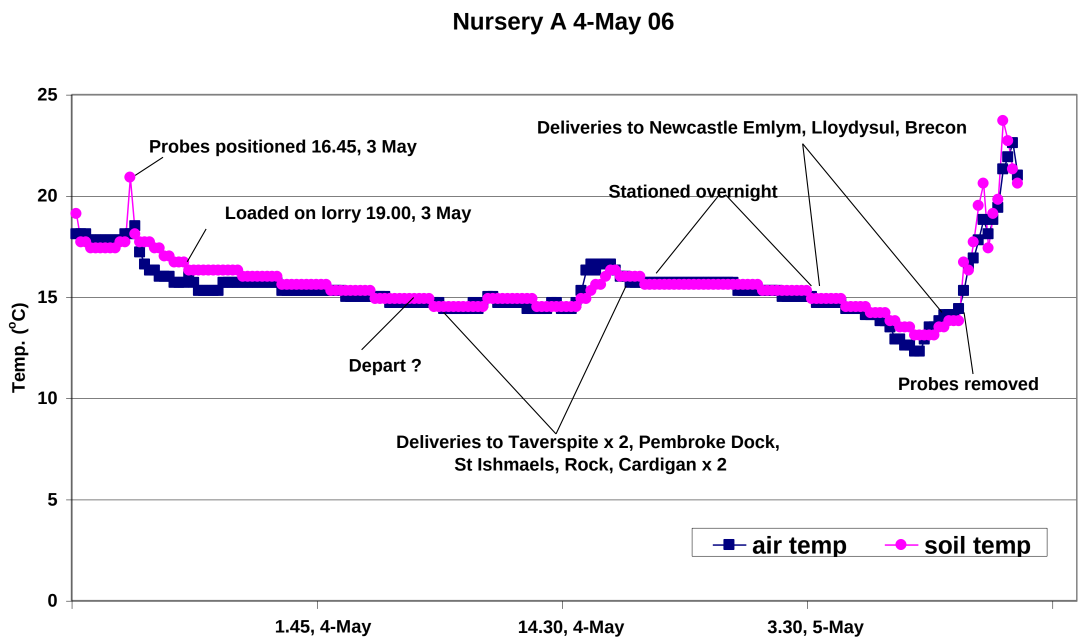
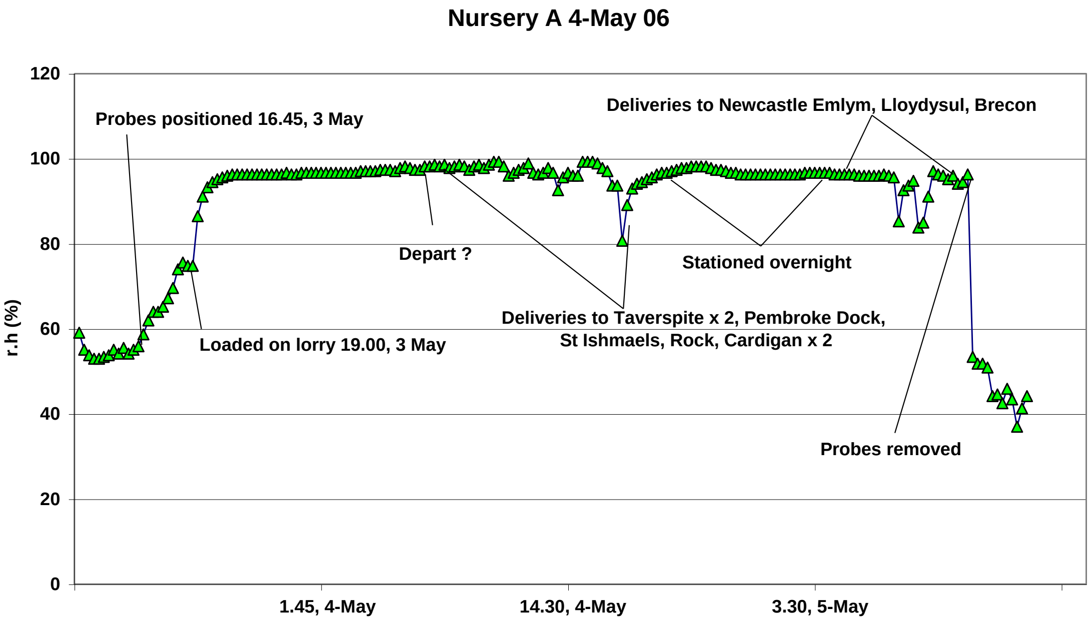


**Figure 16. Nursery A - Crop (unknown). Relative humidity. 18 tonne rigid-body, refrigerated lorry, but run at ambient. Two day run, with final = Brecon, Powys.**




Possibly the most interesting aspect of this run was the fact that plants were held in the dark, for about 42 hours at moderate temperatures (15$^{o}$C) and high humidity. Unfortunately, there is no data on crop quality after this run.

There were no consistent differences, in data sets and questionnaire results, between those runs recorded in autumn and those in spring / summer. Those nurseries without refrigerated lorries appeared to load early in the morning during the summer, just an hour or so before departure, rather than risk keeping the crop enclosed for long periods in warm weather. Where loading was undertaken the night before, then back doors would be left ajar to minimise heat and humidity in the crop. The risk of doing this is that there is no control of night temperature and in this instance one of the lowest night storage temperatures (8.6$^{o}$C) was recorded (despite being in June). Table 3 shows the maximum and minimum temperatures recorded during periods when the wagons were stationary but the crop had been loaded the night before transit (stored), and when on the move. There was no clear evidence of the crop type associated with the 4.8$^{o}$C recording in autumn, but it is likely to have been a hardy species as it was a November delivery.

**Table 3. Highest and lowest temperature recorded during storage the evening prior to departure, or during transit in both the autumn and spring / summer recording periods. (Data represent stabilised temperatures within each environment)**

| Measurement | Autumn ($^{o}$C) | Spring / Summer ($^{o}$C) |
|---|---|---|
| Max. Night temp (stored) | **19.5** | **22.6** |
| Min. Night temp (stored) | **16.3** | **8.6** |
| Max. Transit temp | **18.8** | **26.8** |
| Min. Transit temp | **4.8** | **8.6** |

**Exposure to light and darkness**

Strong sunlight in the UK usually equates to 600-1200 µmol $m^{-2}$ $s^{-1}$. Depending on the type of plant and type of leaf ('shade leaves' are more efficient) most light compensation points (when energy gained is equal to energy lost through respiration), occur between 10 and 85 µmol $m^{-2}$ $s^{-1}$. In hubs and dispatch areas, light levels at crop canopy level were recorded in the region of 5-10 µmol $m^{-2}$ $s^{-1}$. In the middle of a full trolley, they were 0-0.5 µmol $m^{-2}$ $s^{-1}$. Therefore, it is unlikely that plants were photosynthesising during transit, or during periods where they were left on trolleys in artificially illuminated dispatch areas. Hence, in terms of photosynthesis, most plants would effectively be 'in the dark' from the point they were moved from the glasshouse and until they were placed on a retail bench at a garden centre.

**Ethylene ($C_2H_4$) and other data from hub**

A number of visits were made to a retailer's delivery and dispatch centre (hub) to monitor crop quality and ethylene released from crops after the initial phase of transport. The hub is a location where plants are received from the nursery (sometimes via a haulage company) and then sorted, stored and re-distributed to the retailer's own stores. This can extend the period crops are in transit, although most retailers will aim to re-distribute them within 24 hours of arrival. Conditions at a hub could be critical in determining final plant quality and information was sought on aspects such as typical temperature, light levels, ethylene levels as well as information on visual quality of crops arriving and departing.

Much of the data collection involved measuring ethylene levels either as background readings or close to the crop canopy. For reference, typical readings for ethylene (at 25$^{o}$C) were outdoors = <0.1 ppm, office environment = 0.6 ppm and single ripening banana (a source of ethylene) enclosed in polythene bag = 6.7 ppm.

Most readings recorded in the hub and around crops were usually in the range 0.5-2 ppm ethylene, although on occasions levels could exceed these. The highest recorded level of ethylene was associated with some discarded Christmas trees placed near the enclosed end of one of the hub bays. There were no bedding plants in this bay at this point, but the levels released from these decaying trees (22 ppm) were well in excess of those quoted in the literature as being phytotoxic to many plant species.

Even when bedding plants were the only crop type being handled, their position within the bay had an effect on background readings. There were two heating fans (electrical, so unlikely to be contributing to ethylene levels directly) located near the loading gates, and often highest ethylene readings were recorded here when a loaded trolley was stood in line with the fans. This was the area that trolleys were stood out after unloading and before being collected for de-stacking. Trolleys stood here for approximately 10-15 minutes before being moved on. Ethylene derived from the crops was also often highest around this location, i.e. once the crops were removed from the relative cool (but enclosed) lorry environment to this open, but warmer area (Figure 17). A number of crops (such as pansy in flower), but by no means all, showed this type of ethylene release trend.
Repeated measurements were taken across a range of crop types and in different locations to assess mean ethylene levels. Locations selected were: i. background in the wagon, ii. crop canopy in the wagon before unloading, iii. crop canopy in the hub 10 minutes after unloading and iv. crop canopy in hub 30 or more minutes after unloading. The data showed there was a significant increase in ethylene concentrations after the crops had been placed in the warmer hub environment for more than 30 minutes, compared to the background and crop levels in the (cooler) wagon (Figure 18). Background levels in the hub itself were variable (0.5 to 1.2 being typical) and were dependent on factors such as volume of crop present, ambient temperature of the hub and the extent to which the bay doors were open. The data again suggest that recorded ethylene levels in the cooler wagons is relatively low, but that more ethylene becomes expressed once the crop is moved into the warmer environment of the hub. The build up of ethylene levels around the crop may be made worse when bay doors are closed (minimizing ventilation), and ambient temperatures are high.

There was considerable variation in ethylene levels, however, on crop type, how long the crop had been in the hub, type of packaging used and whether the crop was in flower. Figure 19 highlights some of the variations recorded on the 1 June 2006. It was noted that relatively high levels were associated with the presence of a mechanised (diesel) sweeping machine, and a crop of trailing *Pelargonium* where the media was dry. Interestingly, *Impatiens* crops also often demonstrated a relatively high ethylene reading.

**Figure 17. Hub Location, Warehouse A – Bedding and herbaceous plants (5 April 2006). Ethylene readings at various locations in a potted pansy (*V. x wittrockiana*) crop (non-enclosed) over time.**

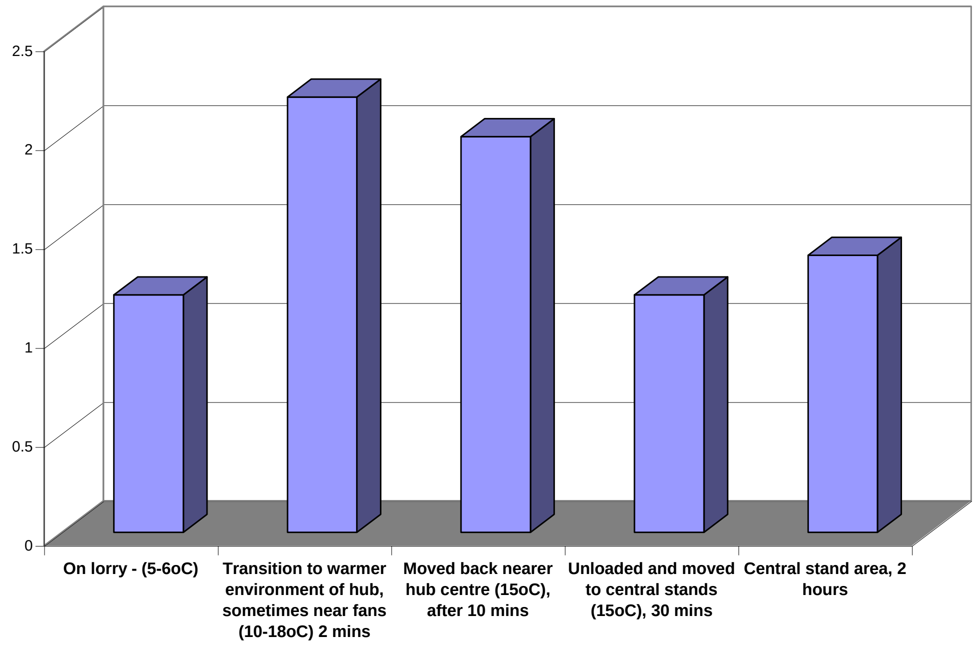



**Figure 18. Hub Location Warehouse A – Bedding and herbaceous plants (5 April 2006). Ethylene readings from different locations averaged across a range of bedding crops and time. LSD at P<0.05, d.f.=64.**

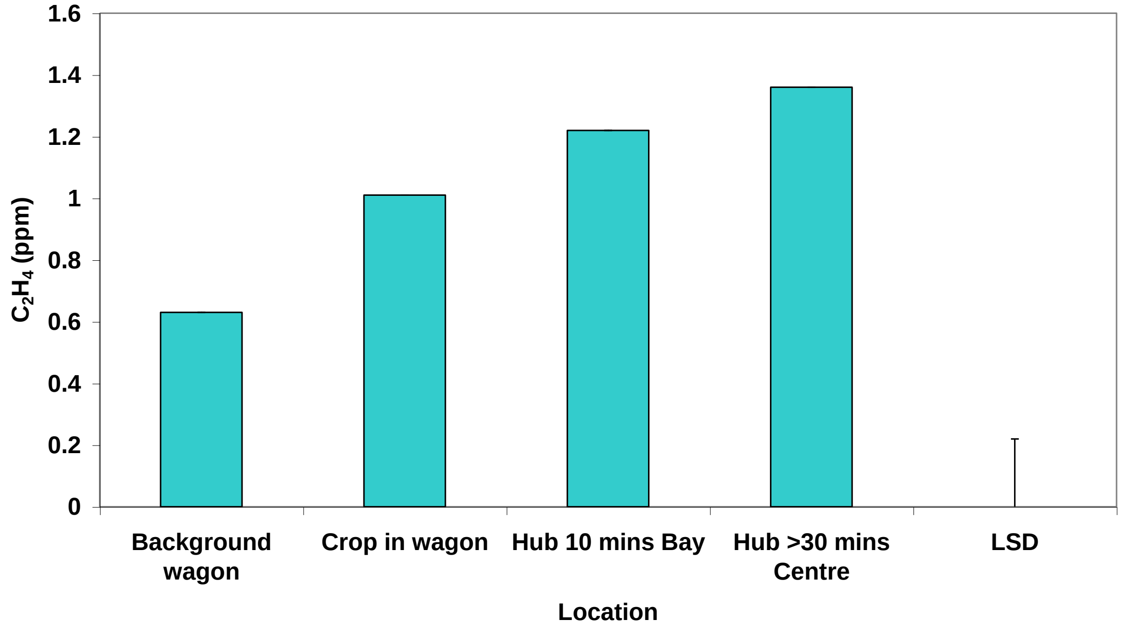
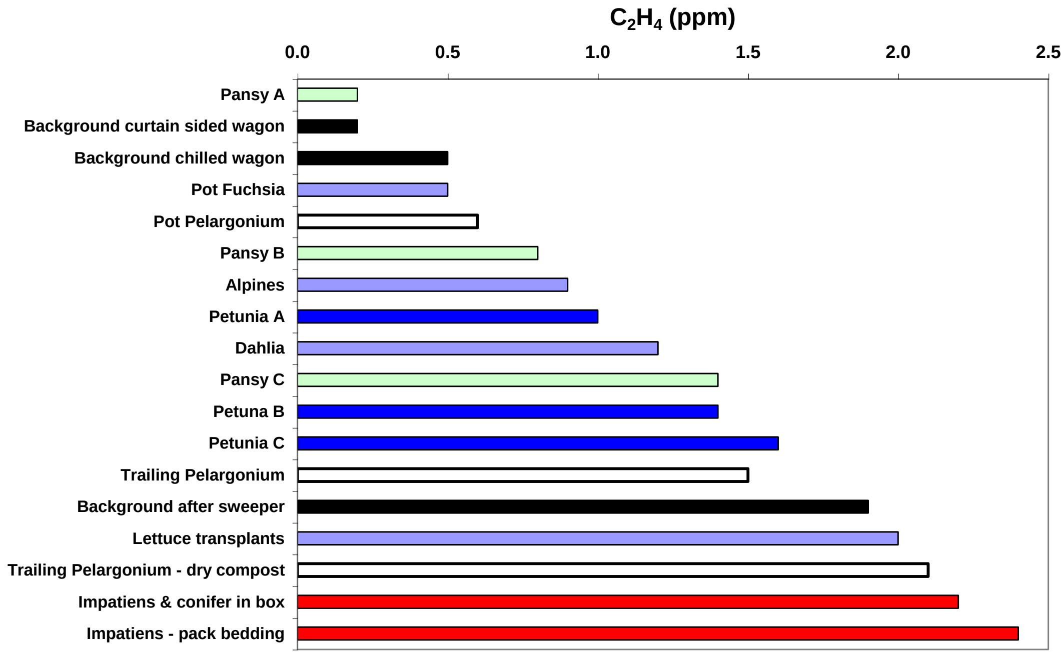


**Figure 19. Hub Location, Warehouse A – Bedding and herbaceous plants (1 June 2006). Ethylene readings from different crops and locations. Temperature varied between 7 and 20°C.**




## Experiment 2 (Year 2)

**Temperature and duration of transport conditions using autumn and spring bedding.**

The aim of this experiment was to determine how plant quality was affected when transport conditions were simulated using controlled facilities to recreate realistic scenarios for transport. Variables investigated included temperature (12°C vs 22°C) duration (24 vs 48 hours) and whether the crop canopy was wet or not during the storage period. The experiment included bedding plant types commonly distributed in autumn and in spring.

Ethylene readings were highest during the autumn experiments, but the peak recording was only 1 ppm (Figure 20). 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.

Most injury and loss of plant quality was associated with the longer duration storage (Figures 21-26), although species responded to temperature in different ways. Higher temperatures for the 48 hour duration was detrimental to Pansy, (both winter, Figure 21 and spring, Figure 22), Petunia (Figure 23) and to a limited extent Impatiens (Figure 24). In contrast, plant quality suffered more at the lower temperature of 12ºC in Cyclamen (Figure 25) and Polyanthus (Figure 26).

Reasons for loss of quality also varied between the species. The higher temperature and prolonged storage resulted in leaf yellowing and etiolation of the shoot tips in Pansy and Petunia, resulting in reduced scores for size and habit parameters (Table 4). In Cyclamen, 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 12ºC Wet 48 hour treatment without any direct evidence of *Botrytis* (Figure 27). Polyanthus plants were fairly variable before the experiment with each treatment having 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 12ºC treatments. Older leaves under the canopy were particularly prone to yellowing. Of the species tested, Impatiens appeared the most resilient and there was little injury noted *per se*. However, plants in the warmer treatment for the longer duration tended to become overlarge and lose uniformity.

**Figure 20. 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.***

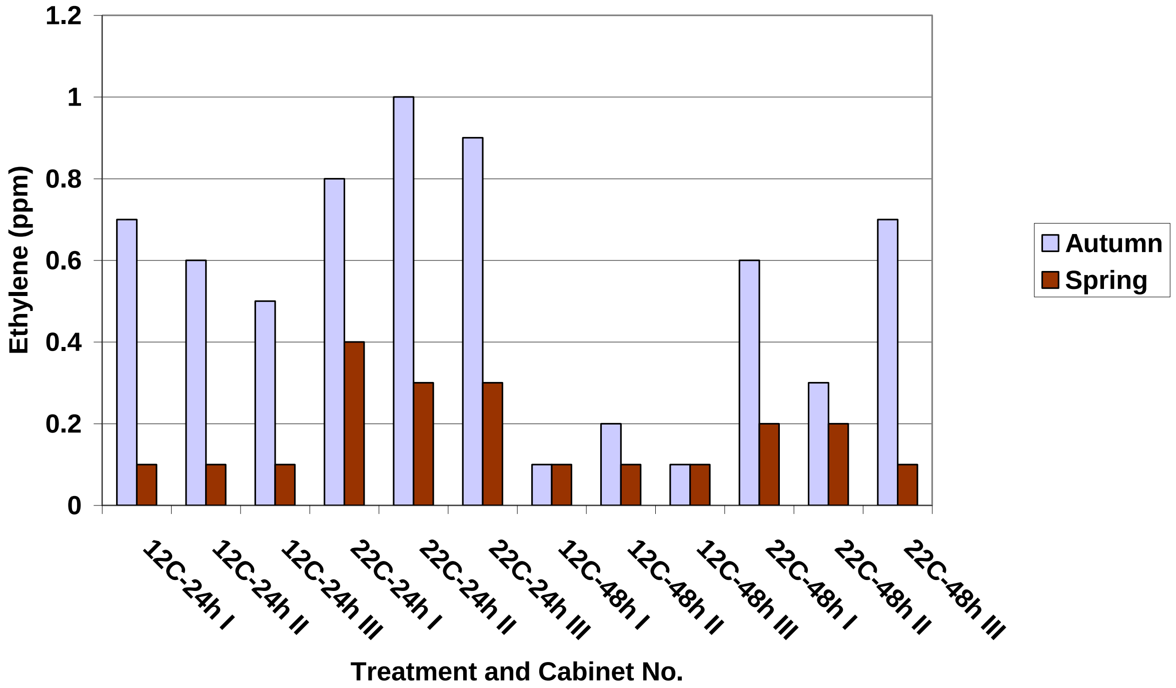



**Figure 21. Winter Pansy – Quality score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.**

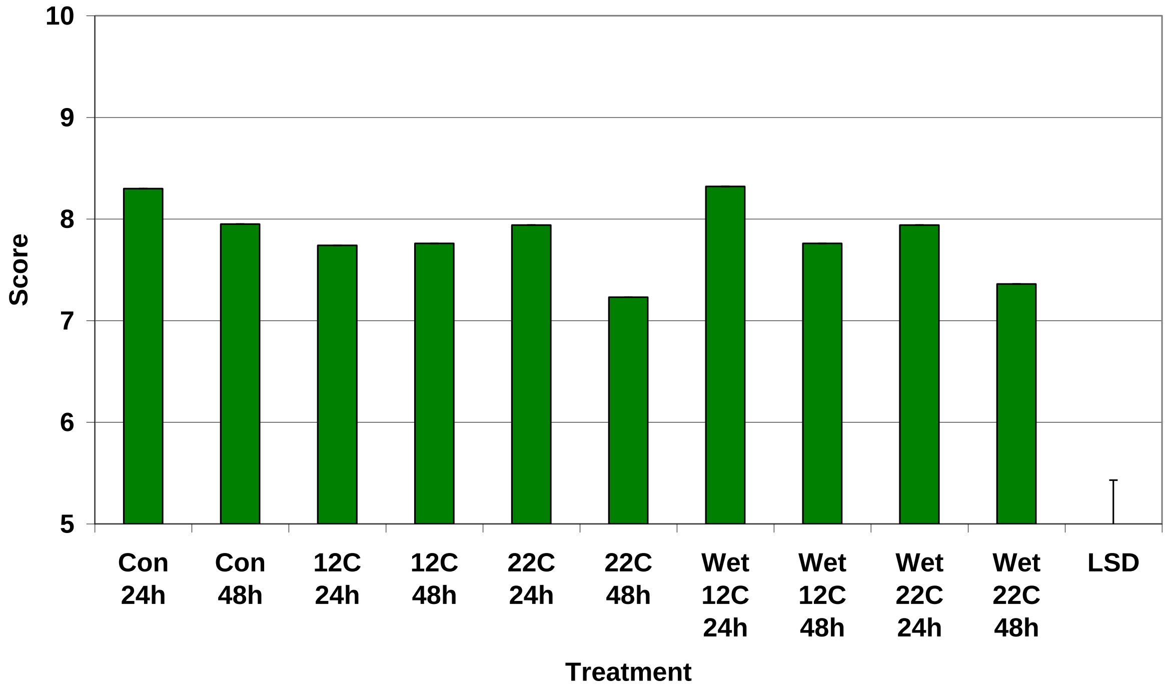


**Figure 22. Spring Pansy – Quality score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.**

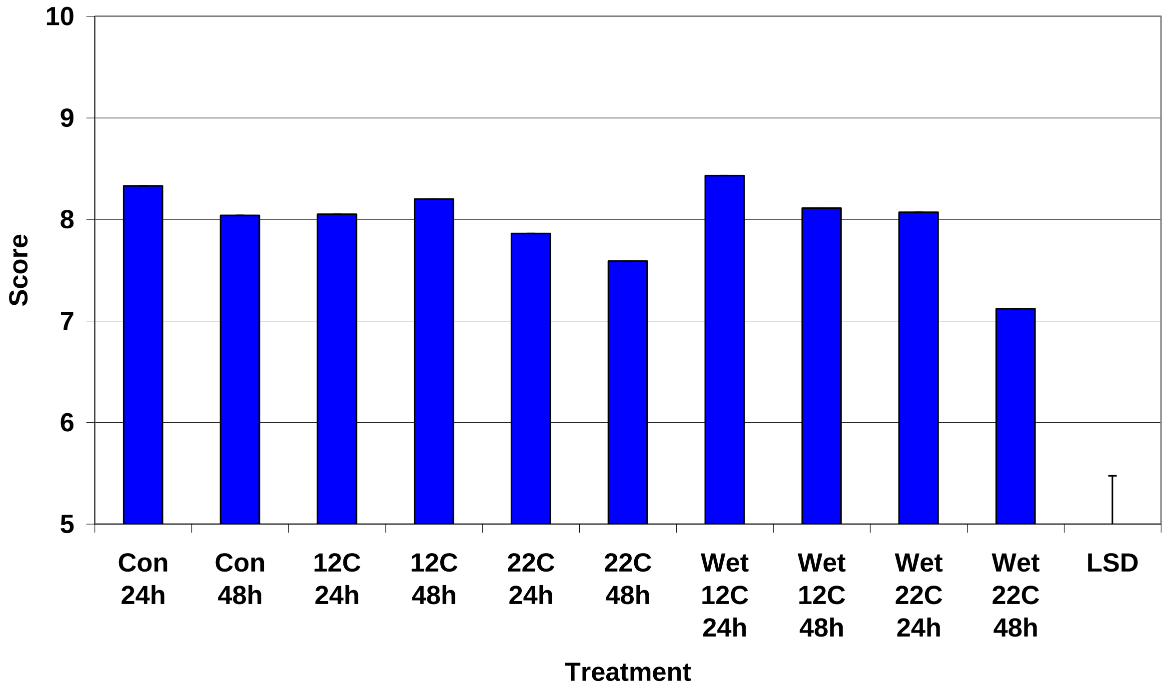



**Figure 23. Petunia – Quality score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.**

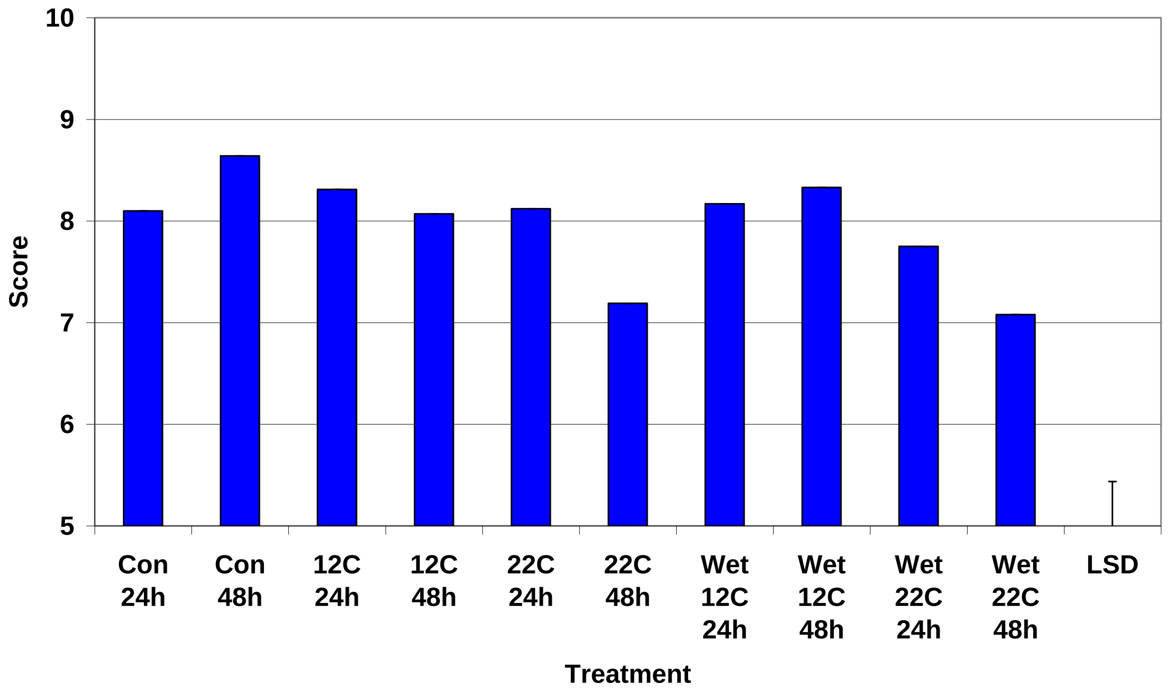


**Figure 24. Impatiens – Quality score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.**

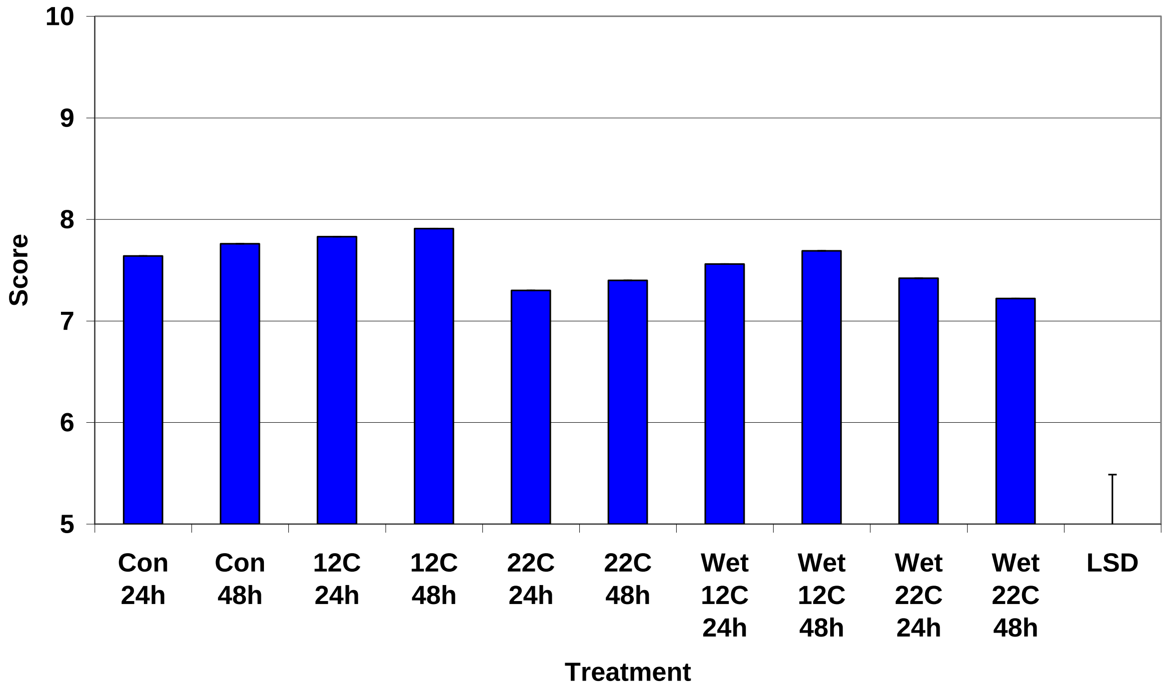



**Figure 25. Cyclamen – Quality score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.**

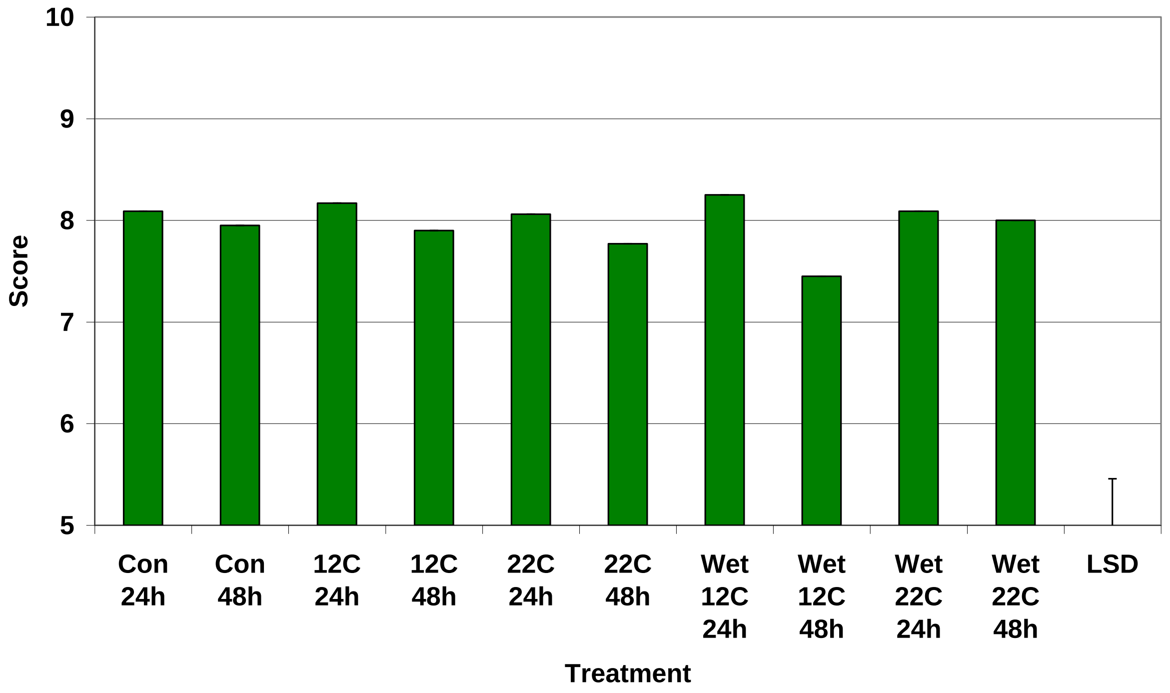


**Figure 26. Polyanthus – Quality score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.**

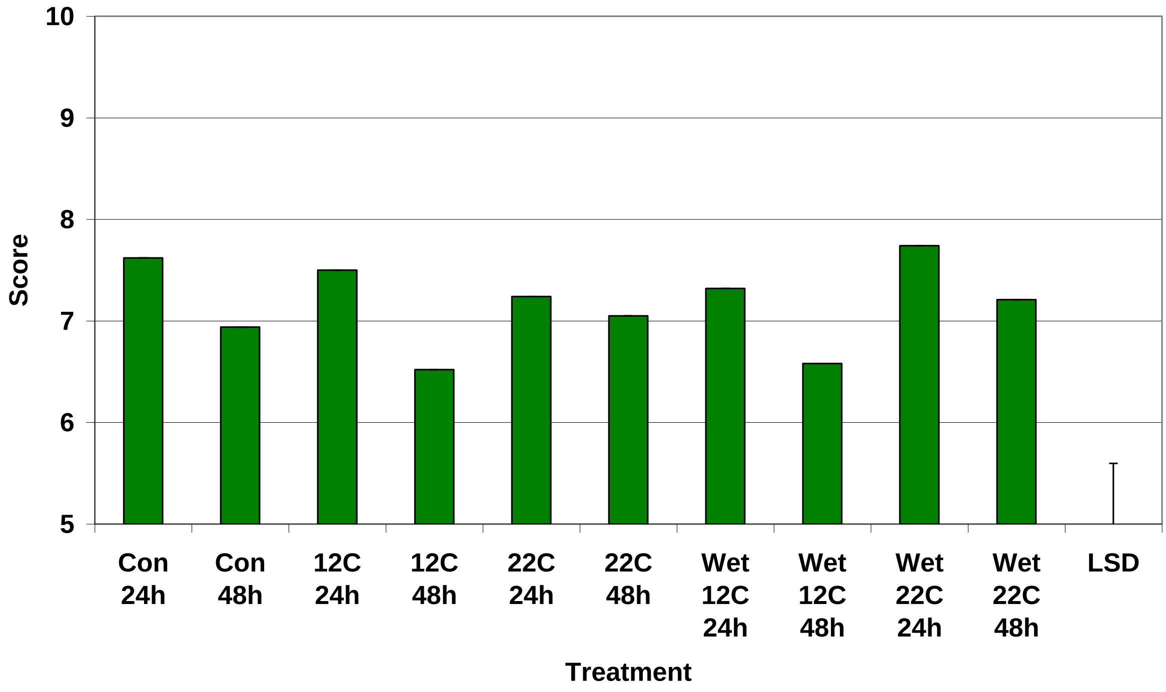
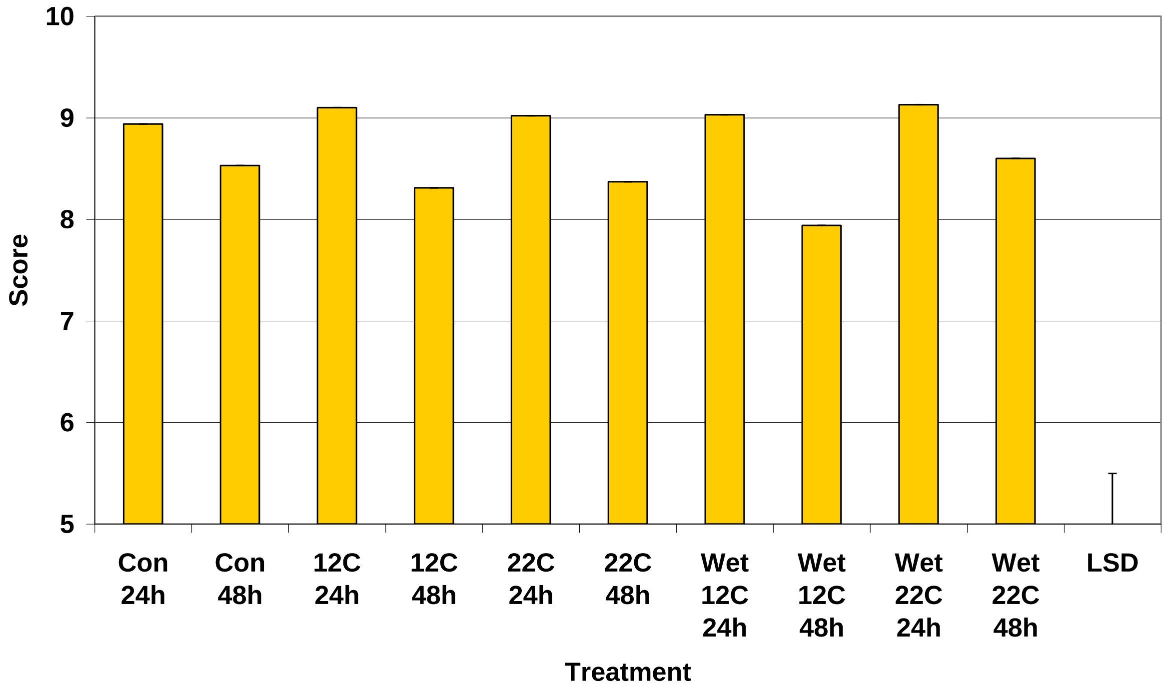



**Table 4. Mean scores for crop size and habit in Spring Pansy and Petunia. Some plants retaining wet foliage throughout.**

| | | | Con | 12 C | | 22 C | |
|---|---|---|---|---|---|---|---|
| | | | | | Wet | | Wet |
| Spring Pansy | Size | 24h | 2.2 | 2.1 | 2.4 | 1.9 | 2.5 |
| | | 48h | 2.0 | 2.3 | 2.3 | 1.9 | 1.7 |
| | | | | | | LSD = 0.38 | |
| | Habit | 24h | 2.5 | 2.3 | 2.2 | 2.2 | 2.2 |
| | | 48h | 2.4 | 2.4 | 2.1 | 1.9 | 1.9 |
| | | | | | | LSD = 0.27 | |
| Petunia | Size | 24h | 2.4 | 2.5 | 2.5 | 2.1 | 1.9 |
| | | 48h | 2.4 | 2.5 | 2.3 | 1.8 | 1.5 |
| | | | | | | LSD = 0.42 | |
| | Habit | 24h | 2.2 | 2.5 | 2.3 | 2.2 | 1.9 |
| | | 48h | 2.4 | 2.3 | 2.3 | 1.6 | 1.6 |
| | | | | | | LSD = 0.24 | |

**Figure 27. Cyclamen – Plant health score after storage at different temperatures and durations and with some plants retaining wet foliage throughout.**




**Experiment 3 (Year 2)**

**The rapid transition of bedding plants from wagons to high light and temperature conditions outdoors**

The focus of this experiment was to recreate the situation where bedding plants were moved from the dark (and sometimes cool) interior of the wagon and stood out on a warm summer's day, e.g. on a garden centre display bench. Could the rapid transition in temperature and light be a possible source of injury to plants? Again extra factors such as level of water of the foliage or dryness of the media were explored.

Results showed quality scores were quite variable for the Petunia (data not shown), but this was more to do with variations between individual trays, rather than any strong treatment effect (i.e. any treatment effects were being masked by relatively high levels of existing variation between trays in the crop). This initial variability remained despite careful grading of trays before the experiment and the use of analyses of co-variance to help reduce 'background' variability. However, when one factor associated with reduced quality, i.e. yellowing of the shoot tips, was isolated in the analysis, there was a strong correlation between higher storage temperature and this physiological disorder (Figure 28).

Treatment effects were more obvious in Impatiens. This species was susceptible to wilting and loss of quality in the dry treatment at 35ºC (Figures 29). 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).

**Figure 28. 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).**

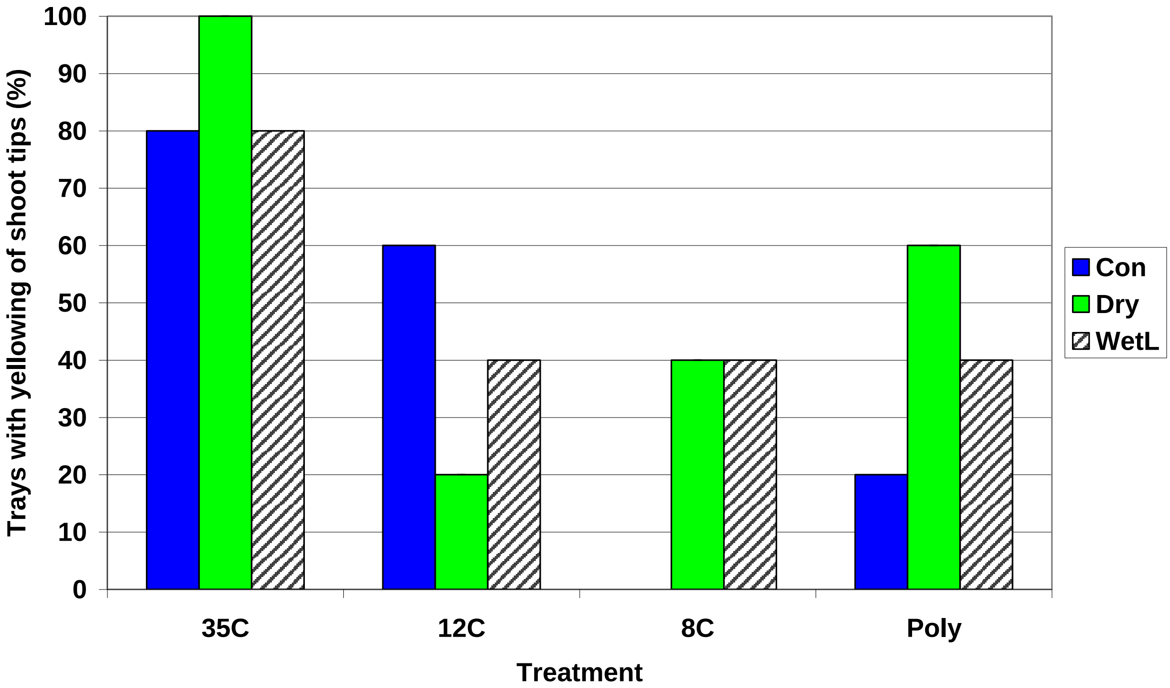
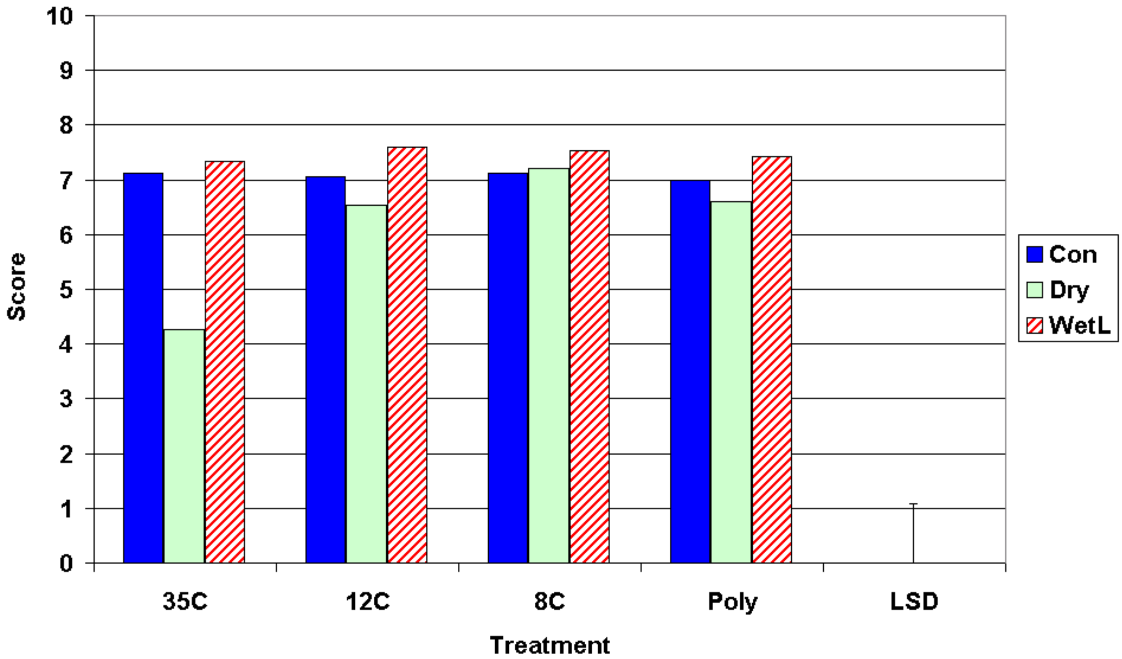


**Figure 29. Impatiens – Quality score after storage at different temperatures with plants either watered 2 hours (Con) or 24 hours (Dry) before treatment, or retaining wet foliage throughout (WetL).**




**Experiment 4 (Year 2)**

**Controlled temperature and light combinations**

This experiment was designed to see if there were interacting effects between temperature transitions and the presence of light. Results gave little indication that rapid transition *per se* from dark to light or from cool to warm temperatures caused damage directly. Only those treatments that were linked to drying of the medium combined with high temperature showed strong adverse effects on plant quality, and this was due to direct drought stress. Impatiens, with its relatively high water requirement was particularly susceptible in this scenario (Figure 30), although Petunia also showed similar symptoms in the 8D-35L treatment (Figure 31), when watering had been withheld for 24 hours previously.

**Figure 30. Impatiens – Quality score after storage and movement between different temperatures and light levels.**

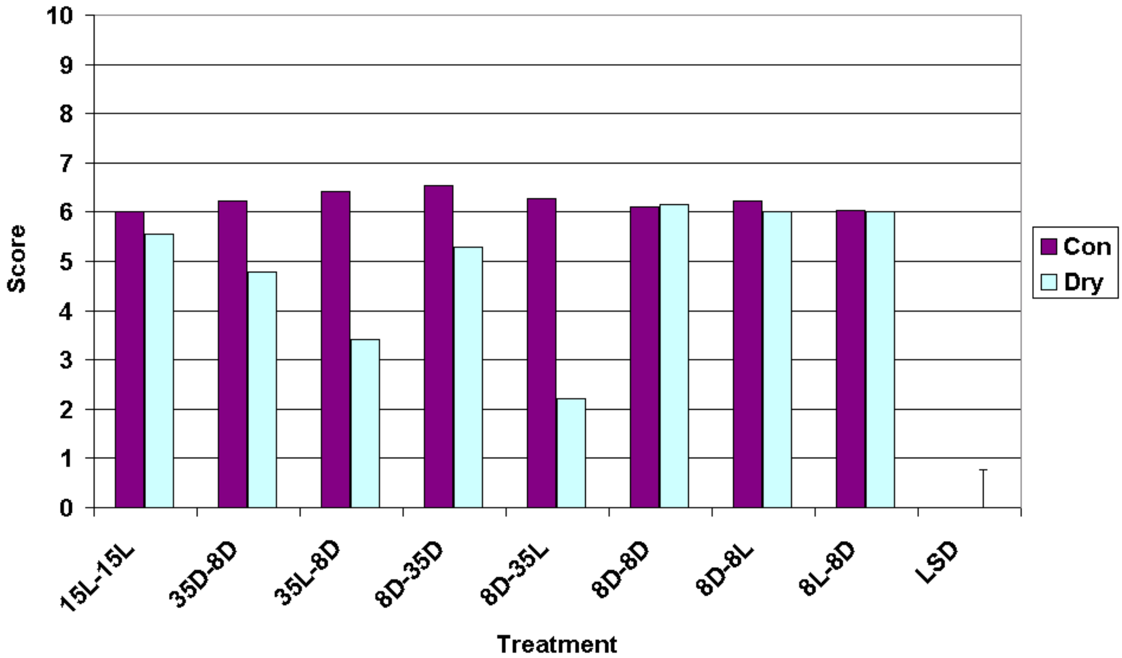
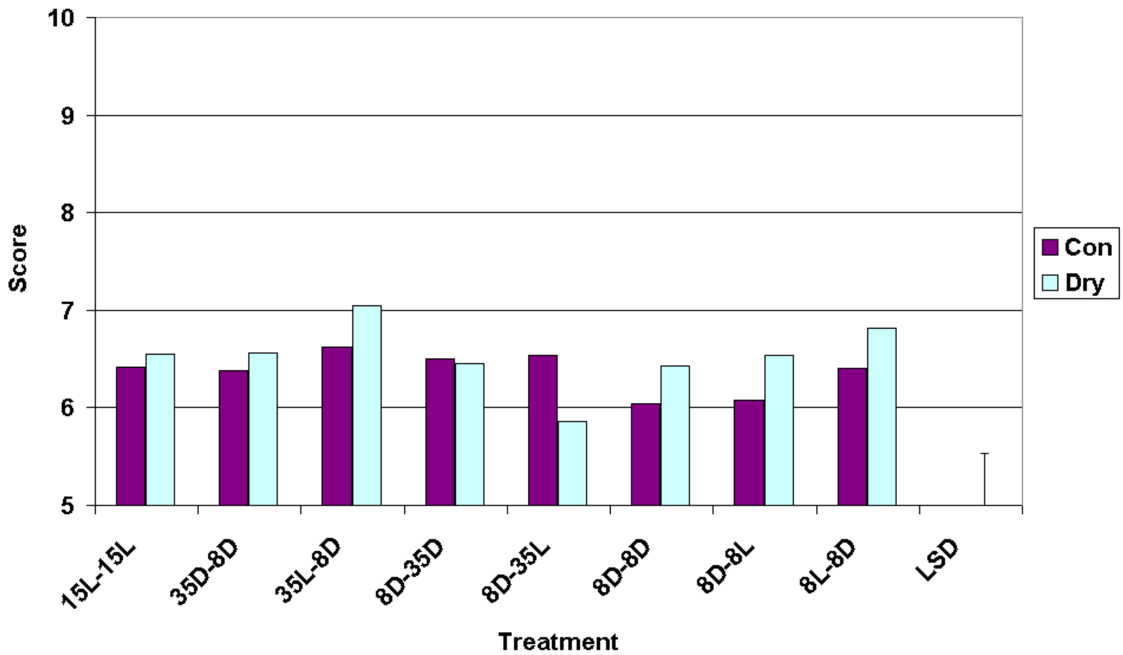



**Figure 31. Petunia – Quality score after storage and movement between different temperatures and light levels.**



**Experiment 5 (Year 2)**

**The effect of relative humidity on crop quality during transportation**

The aim here was to determine if high humidity was detrimental to plant quality during storage at different temperatures and durations. Figures 32-35 show mean data including the control group of plants. Removing the control group data allowed factorial analyses to be attempted. This showed that humidity and duration were the main factors affecting plant quality and health scores in Petunia. For quality scores there was a strong interaction ($P<0.001$) between humidity and duration i.e. the effects of high humidity were more detrimental only after the prolonged duration of 48 hours. In terms of health scores, however, high humidity was having a significant effect both at the 24 and 48 hour durations. In Petunia, plants demonstrated either flaccid, dull olive coloured older leaves, or some yellowing of the new leaves. The flaccid leaf symptom was worst in the high humidity treatment for 48 hours (irrespective of temperature). Even at the shorter 24 hours high humidity treatments, flower quality could be compromised too, with petals displaying a wilted appearance (Table 5).

In Impatiens there were significant interactions between all three factors, but it was evident that increasing duration resulted in a loss of plant quality ($P<0.001$), and that higher humidity had a detrimental effect over the 48 hour storage period (Figure 34). Plants displayed shoot-tip yellowing and rolling of the new leaves in the 22$^{o}$C high humidity treatment (Figure 35). These leaf symptoms were short-term however, and in a number of trays these symptoms had largely disappeared by the following assessment 24 hours later.

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 36). Whether the higher (but still relatively low levels) associated with the high humidity environments was contributing the loss of flower (Petunia) or leaf quality (Impatiens) is not clear.

**Figure 32. Petunia – Quality score after storage at different temperatures, humidity and durations.**

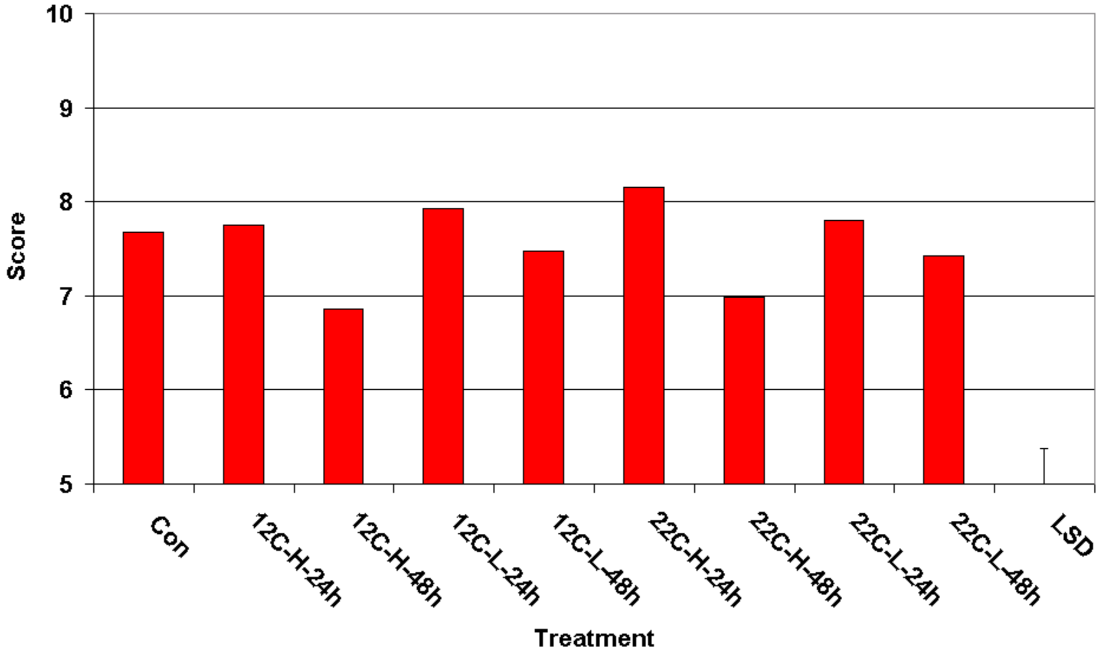



**Figure 33. Petunia – Plant health score after storage at different temperatures, humidity and durations.**

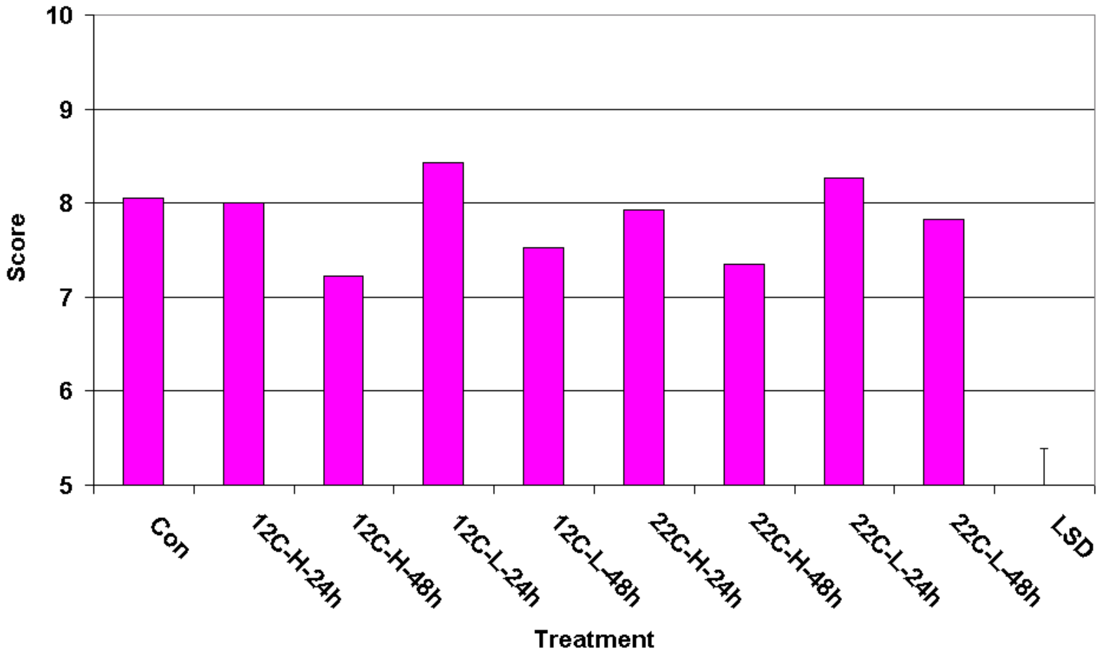



**Figure 34. Impatiens– Quality score after storage at different temperatures, humidity and durations.**

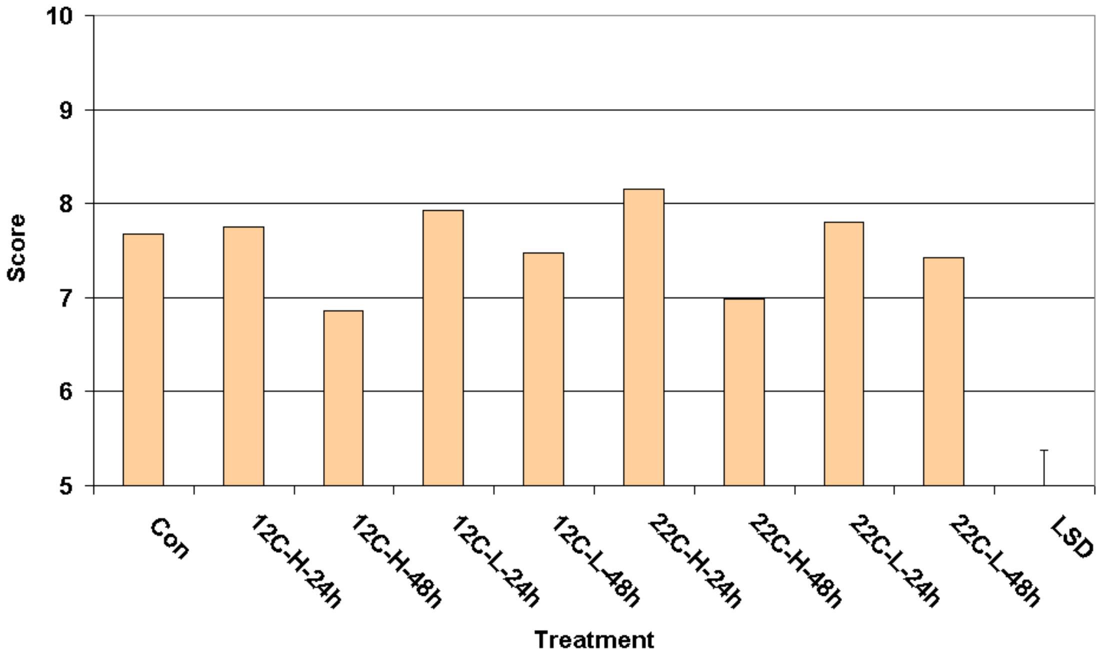



**Figure 35. Impatiens– Plant health score after storage at different temperatures, humidity and durations.**

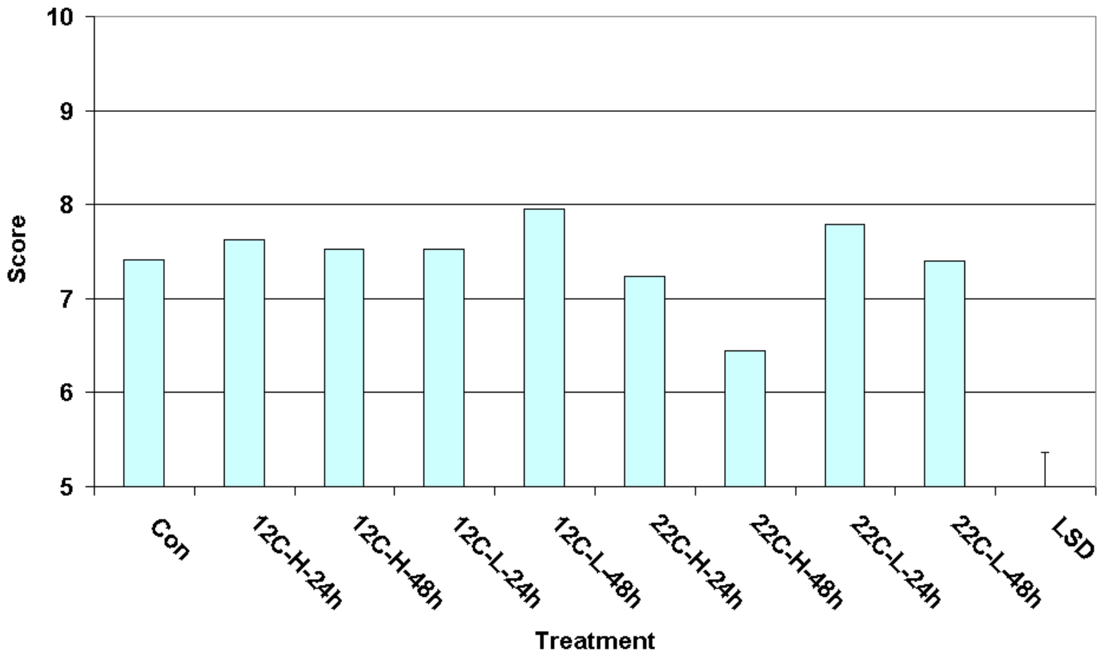
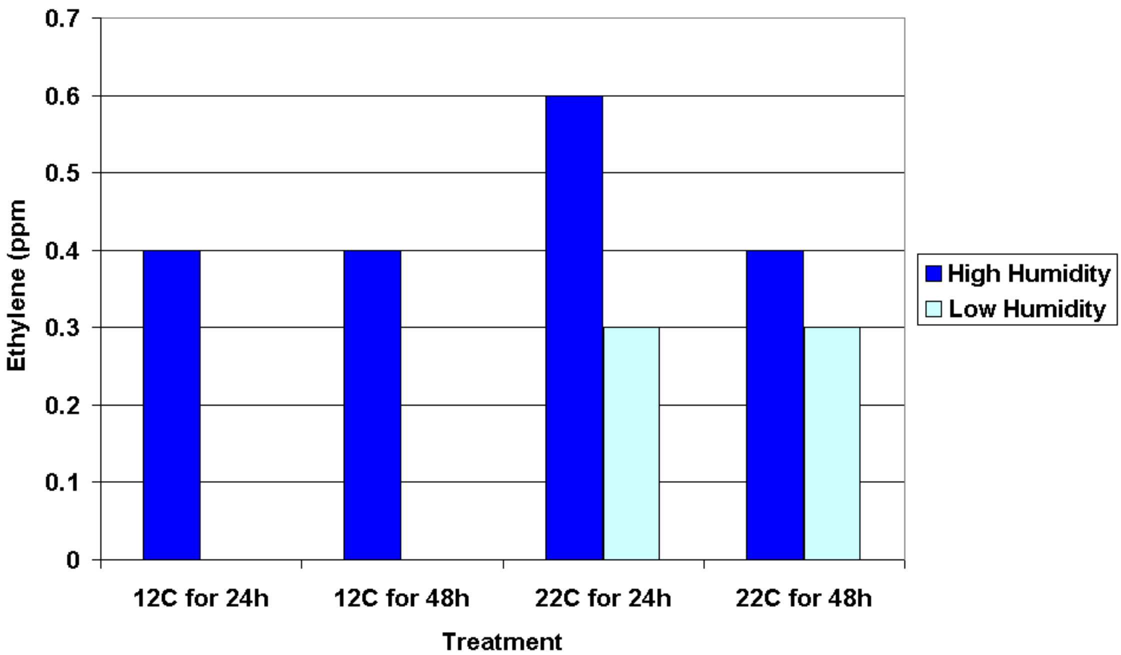



**Table 5. Petunia – Mean scores for flower development after storage at different temperatures, humidity and durations.**

| | Con | 12C | | 22C | | LSD |
|---|---|---|---|---|---|---|
| | | High | Low | High | Low | |
| 24h | 2.28 | 1.61 | 2.08 | 1.80 | 2.46 | |
| 48h | | 1.48 | 1.89 | 1.13 | 2.19 | 0.405 |

**Figure 36. 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.***




**Experiment 6 (Year 2)**

**Influence of transporting crops in polythene-wrapped Danish trolleys or in cardboard boxes**

There was no consistent response between species when they were stored on Danish trolleys, either open, in boxes or within polythene wrapping. Lower quality scores were recorded in Pansy when the crop was left open (Figure 37), but the reasons for this was not clear. It may possibly have been an affect of the air distribution fan within the cabinet that was used to circulate the air (the open plants being more exposed to air movement). There was no loss of quality noted in the very uniform crop of Dianthus (data not shown), but with Cyclamen there was a slight reduction in overall quality associated with the 12°C Polywrap treatment (Figure 38), due largely to a poor growth habit in a small number of the trays. There were also some limited incidences of *Botrytis* and leaf yellowing associated with the 22°C Boxed plants.

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 (for example within the polythene wrapped trolleys the recording was 0 ppm at 12°C, but 1.1 ppm at 25°C). Levels were generally lower with Dianthus and Cyclamen (Max. = 0.6 ppm) and this may have related to greater proportion of flowers associated with the Pansy crop (15-18 blooms per tray compared to 2-3 per tray).

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

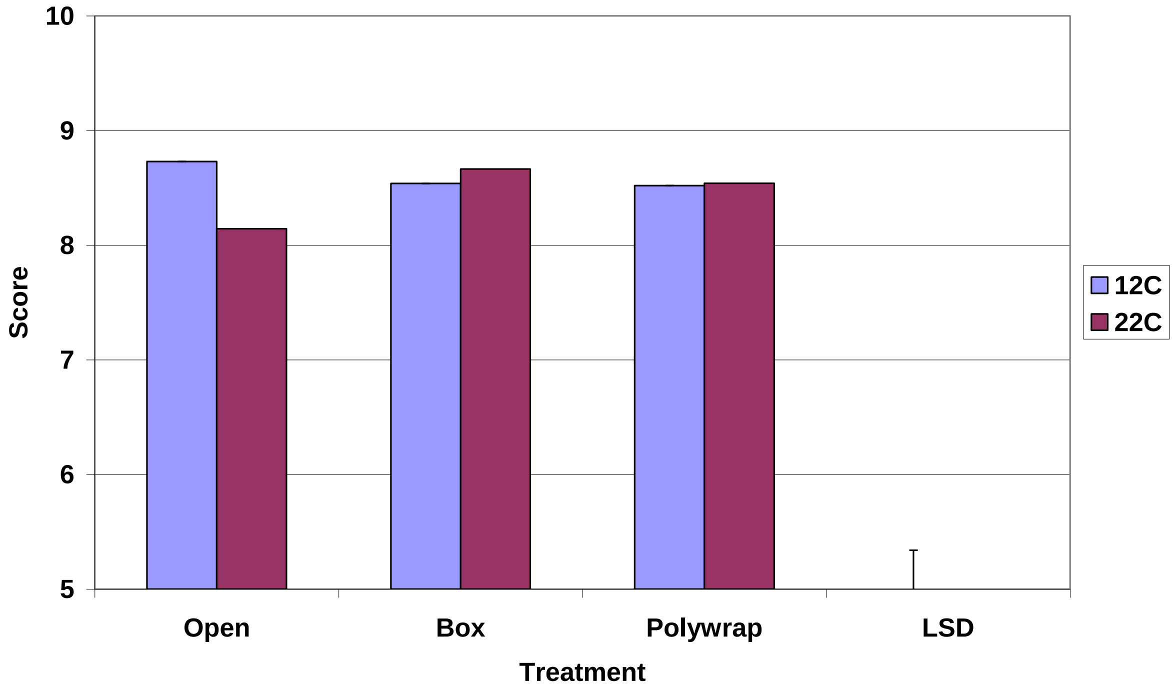
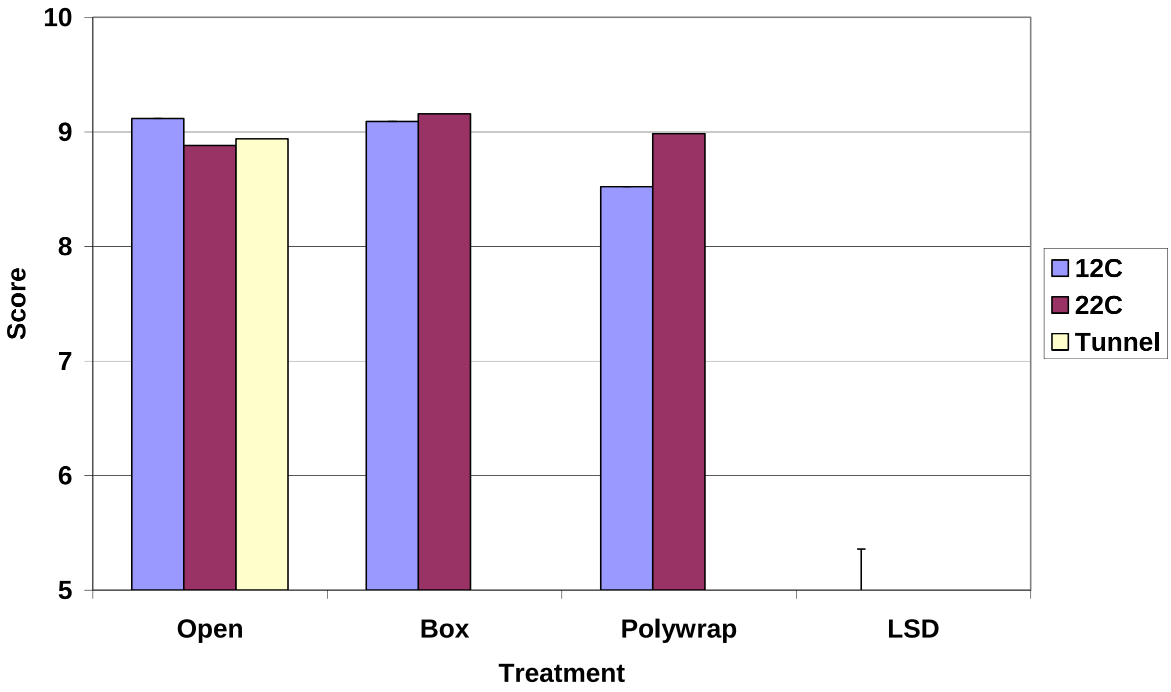



**Figure 38. Cyclamen – Quality score after storage either open, within boxes or within polythene-wrapped Danish trolleys.**




**Experiment 7 (Year 3)**

**Does crop pre-treatment (toning) help retain quality during transportation?**

The objective of this experiment was to determine if cultural techniques during the production phase could help improve plant robustness prior to transportation, thereby reducing the likelihood of injury or loss of quality.

**Petunia**

Treatments showed marked effects on plant quality even before plants were placed in storage. The $PO_3$ treatment was particularly detrimental at the concentrations applied, with plants demonstrating chlorotic leaves and flower discolouration (Figures 39 and 40). Placing plants in storage accentuated the poor flower quality in this treatment (Figure 40). Plants in the Controls (including those moved to the Polytunnel), Cool, Growth Regulator x1 and x2, Brushed, Low and High watering treatments all showed fairly good quality parameters before storage. (Figure 39). Quality deteriorated though after storage, notably in Controls, Growth Regulator x1 and x2, the Brushed and the High watered plants. In contrast plants that had previously been maintained on the Low watering regime tended to retain their overall quality (Figure 39).

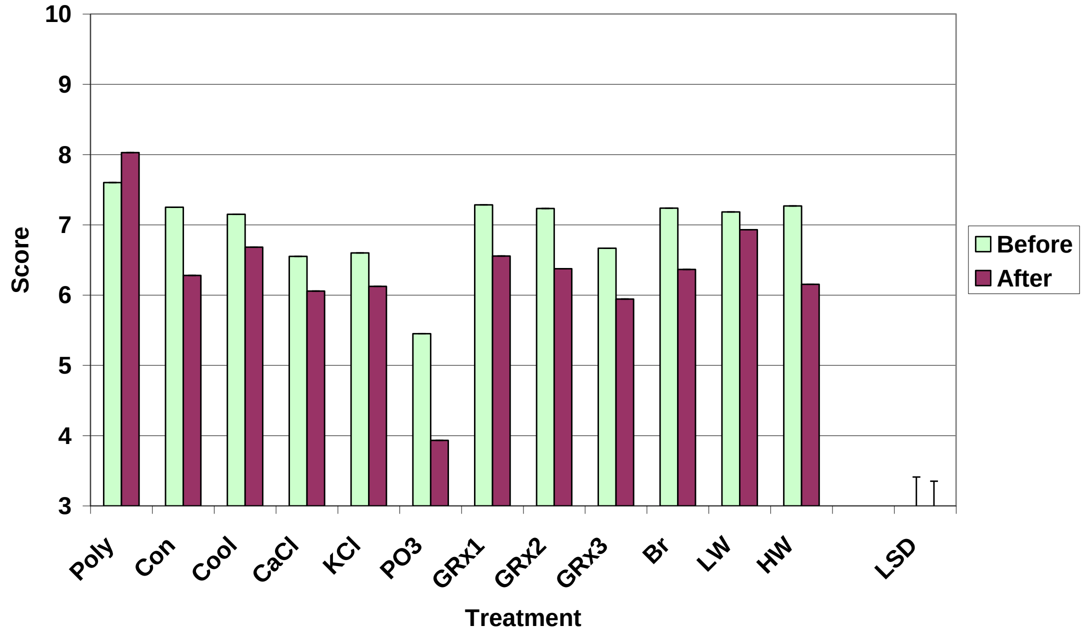
 

The reasons for poor quality varied between the treatments, and again some of these factors related more to the original treatments imposed rather than the storage *per se*. For example quality was generally poor in the CaCl and KCl treatments due to excessive growth during production (Figure 41 & Table 6). Flower development was delayed in the Cool environment, but brought on by the warm conditions in storage, in contrast the good flower quality in the Controls and the High watering treatment was lost, with some petals beginning to senesce. Brushing and Low watering tended to produce plants of good habit under the glasshouse conditions (albeit the plants on Low watering were considered somewhat undersized in the initial assessment). In general, however, the plants from the Low watering regime tended to keep their quality aspects better than the plants from the Brushed treatment, with the latter showing some shoot extension after the storage treatment (Tables 6 and 7).

The application of growth regulators gave an interesting and sometimes confusing picture. Plants tended to be compact and some trays were uniform (although not all). They tended to show few alterations during storage, except to flower development and quality. By the second assessments though, some scorers were beginning to give them lower scores for plant habit, largely because they were conspicuously shorter (stunted) compared to other treatments. This was particularly the case with those applied with growth regulator on two or more occasions, where it was even evident that flower size was reduced (e.g. compared to Polytunnel plants). It was noticeable over the weeks following the end of the experiment that these plants remained short and may be considered undersized as garden plants. More positively, the treatment applied with growth regulator just once before storage, did retain a good quality appearance at scoring and afterwards.

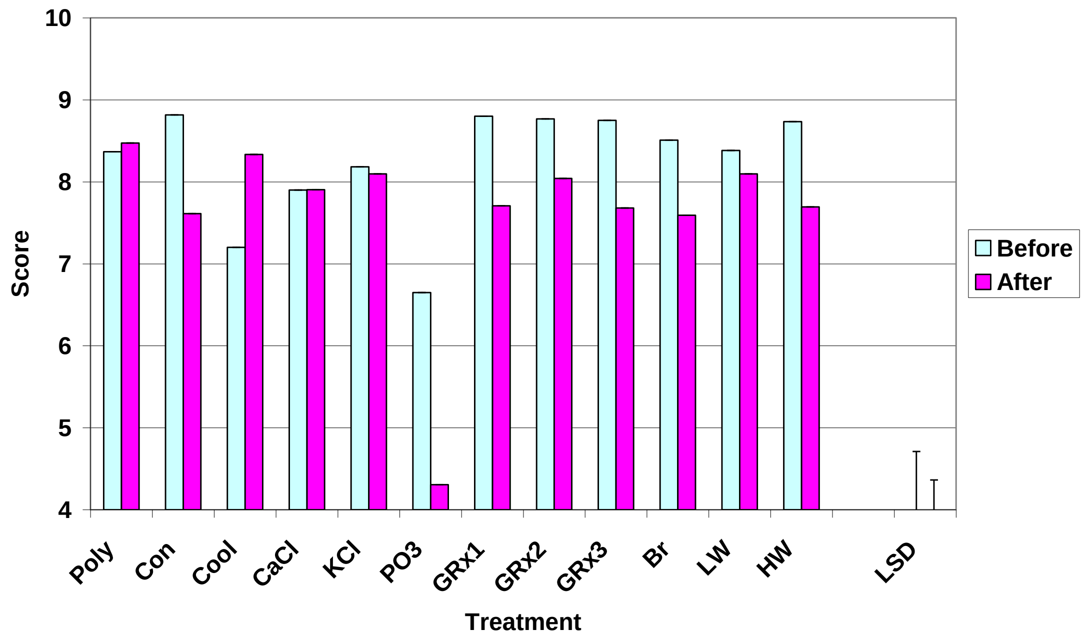
*Potential applications* – Cool grown, Low watering and GRx1.

**Figure 39. Petunia – Quality score before and after storage at 20°C for 48 hours.**



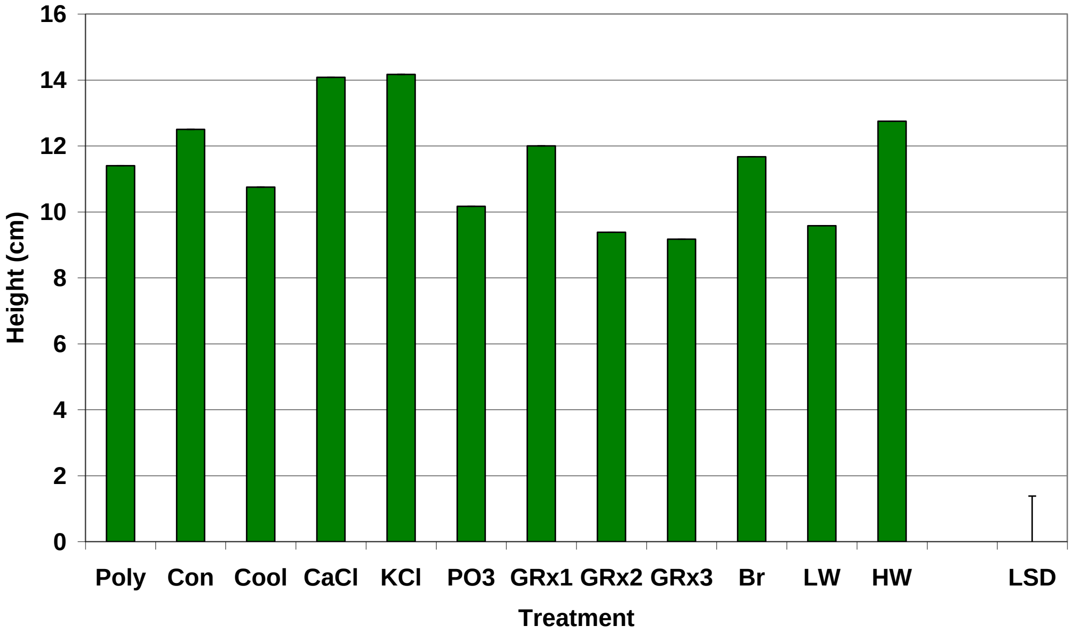

**Key:** Poly = Polytunnel, i.e. no storage; Con = No treatment; Cool = Grown at 2ºC cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 daminozide (B-Nine) applied once; GRx2 daminozide (B-Nine) applied twice; GRx 3 = daminozide (B-Nine) applied three times; Br = Brushed; LW = Low watering; HW = High watering. LSD bars for Before (left) and After (right).

**Figure 40. Petunia – Flower 'health' score after storage at 20ºC for 48 hours.**




**Key:** Poly = Polytunnel i.e. no storage ; Con = No treatment; Cool = Grown at 2ºC cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 daminozide (B-Nine) applied once; GRx2 daminozide (B-Nine) applied twice; GRx 3 = daminozide (B-Nine) applied three times; Br = Brushed; LW = Low watering; HW = High watering. LSD bars for Before (left) and After (right).

**Figure 41. Petunia – Plant height after storage at 20ºC for 48 hours.**




**Key:** Poly = Polytunnel i.e. no storage; Con = No treatment; Cool = Grown at 2ºC cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 daminozide (B-Nine) applied once; GRx2 daminozide (B-Nine) applied twice; GRx 3 = daminozide (B-Nine) applied three times; Br = Brushed; LW = Low watering; HW = High watering. LSD bars for Before (left) and After (right).

**Table 6. Petunia – Mean scores for crop uniformity and size before and after storage, and the relative difference in the scores. (Values in bold represent large changes).**

| Treatment | Uniformity | | | Size | | |
|---|---|---|---|---|---|---|
| | Before | After | *Diff* | Before | After | *Diff* |
| Poly | 2.6 | 2.8 | *0.2* | 2.4 | 2.6 | *0.2* |
| Con | 2.4 | 2.4 | *0.0* | 2.1 | 1.8 | *-0.3* |
| Cool | 2.3 | 2.1 | *-0.2* | 2.8 | 2.6 | *-0.2* |
| CaCl | 2.2 | 2.2 | *0.0* | 1.3 | 1.2 | *-0.1* |
| KCl | 2.3 | 2.3 | *0.0* | 1.3 | 1.2 | *-0.2* |
| PO3 | 2.2 | 2.3 | *0.1* | 2.5 | 2.2 | *-0.3* |
| GRx1 | 2.4 | 2.4 | *0.0* | 2.3 | 2.2 | *-0.1* |
| GRx2 | 2.3 | 2.2 | *-0.1* | 2.7 | 2.7 | *0.0* |
| GRx3 | 2.0 | 2.0 | *0.0* | 2.5 | 2.5 | *0.0* |
| Br | 2.3 | 2.2 | *-0.1* | 2.4 | 1.9 | ***-0.5*** |
| LW | 2.3 | 2.4 | *0.1* | 2.4 | 2.8 | *0.4* |
| HW | 2.3 | 2.3 | *0.0* | 2.1 | 1.8 | *-0.3* |
| LSD | 0.23 | 0.21 | | 0.28 | 0.25 | |

**Key:** Poly = Polytunnel i.e. no storage; Con = No treatment; Cool = Grown at 2ºC cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 daminozide (B-Nine) applied once; GRx2 = daminozide (B-Nine) applied twice; GRx 3 = daminozide (B-Nine) applied three times; Br = Brushed; LW = Low watering; HW = High watering.

**Table 7. Petunia – Mean scores for crop habit and flower development before and after storage, and the relative difference in the scores. (Values in bold represent large changes).**

| Treatment | Habit | | | Flower Development | | |
|---|---|---|---|---|---|---|
| | Before | After | *Diff* | Before | After | *Diff* |
| Poly | 2.4 | 2.4 | *0.0* | 2.1 | 2.2 | *0.1* |
| Con | 2.3 | 2.1 | *-0.2* | 2.0 | 1.4 | ***-0.6*** |
| Cool | 2.7 | 2.2 | ***-0.5*** | 1.5 | 2.4 | ***0.9*** |
| CaCl | 1.8 | 1.8 | *0.0* | 1.8 | 1.9 | *0.1* |
| KCl | 2.0 | 1.8 | *-0.2* | 2.0 | 1.8 | *-0.2* |
| PO3 | 2.2 | 2.2 | *-0.1* | 2.2 | 2.0 | *-0.2* |
| GRx1 | 2.5 | 2.3 | *-0.2* | 1.9 | 1.7 | *-0.2* |
| GRx2 | 2.5 | 2.1 | ***-0.4*** | 2.1 | 2.7 | ***0.5*** |
| GRx3 | 2.1 | 1.9 | *-0.2* | 2.5 | 2.4 | *-0.1* |
| Br | 2.4 | 2.0 | ***-0.4*** | 2.0 | 1.7 | *-0.3* |
| LW | 2.4 | 2.3 | *-0.1* | 1.9 | 2.0 | *0.1* |
| HW | 2.3 | 2.1 | *-0.2* | 2.3 | 1.4 | ***-0.9*** |
| LSD | 0.21 | 0.18 | | 0.34 | 0.3 | |

**Key:** Poly = Polytunnel i.e. no storage; Con = No treatment; Cool = Grown at 2ºC cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 daminozide (B-Nine) applied once; GRx2 = daminozide (B-Nine) applied twice; GRx 3 = daminozide (B-Nine) applied three times; Br = Brushed; LW = Low watering; HW = High watering.

**Impatiens**

Quality was deemed relatively low in the 'salt' treatments (CaCl, KCl and PO3). Plants were generally too tall (see Plate 2). In the GRx3 treatment plants were too small prior to and after storage (Figures 42 and 43). Brushing, Low watering and High watering had no particularly strong effects, either positively or negatively, but generally quality was not deemed to be as good prior to storage in these treatments compared to Controls and Cool grown plants (Figure 42 and Tables 8 and 9).

Loss of quality attributes during storage was particularly evident in plants from the High watering treatment, and to some extent those plants on the GRx2, GRx3 and CaCl treatments (Figure 42). The data on the High watering regime is particularly relevant, because this species tended to be intolerant of drought stress, and generally required good uniform watering to perform at its best. Overwatering would appear to have a negative consequence though, when plants are subsequently placed in the warm humid environment of the cabinets they continued to stretch and became 'overdeveloped' in terms of flower numbers.

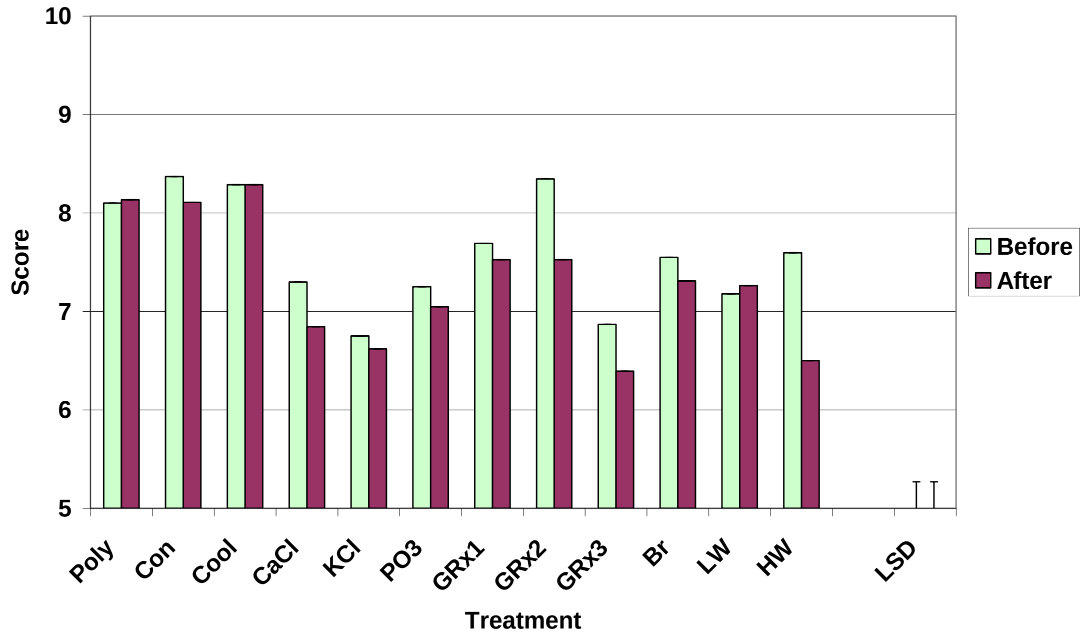
**Plate 2. Impatiens - The application of KCl (right) increased plant height compared to Control plants (left).**


No treatments showed any strong adverse effects on flower or leaf health status (data not shown).

The results from the experiment would suggest that no treatment (Control) or growing plants in a slightly cooler environment (Cool) where the best options available to maintaining quality.

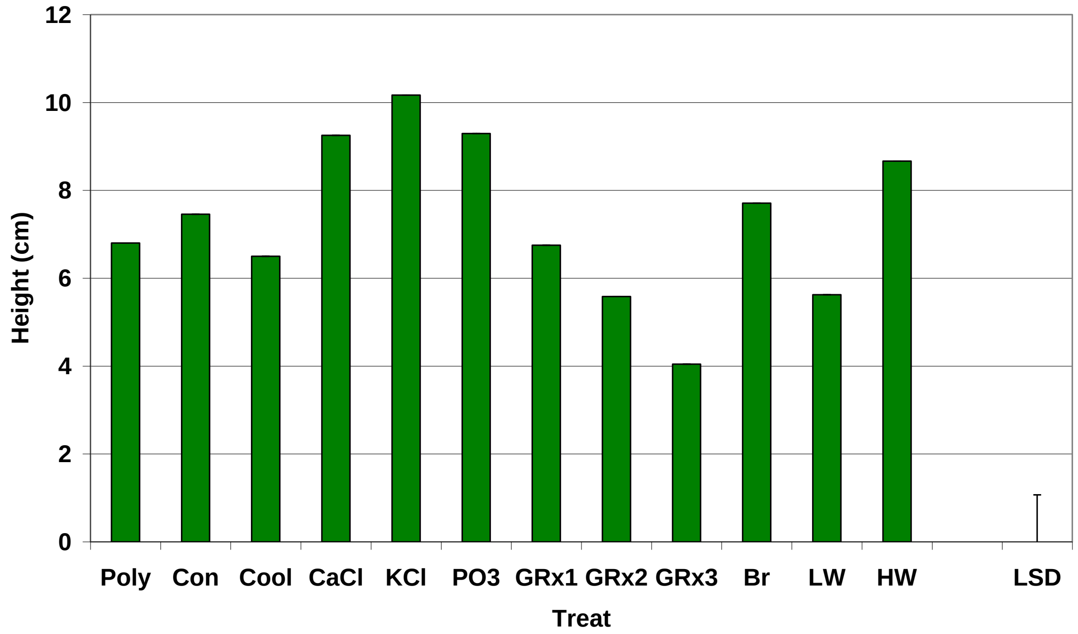
*Potential applications* – Cool grown, or Control (i.e. no treatment, but plants grown such that overwatering is not encountered)

**Figure 42. Impatiens – Quality score before and after storage at 20ºC for 48 hours.**




**Key:** Poly = Polytunnel i.e. no storage; Con = No treatment; Cool = Grown at 2ºC cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 paclobutrazol (Bonzi) applied once; GRx2 = paclobutrazol (Bonzi) applied twice; GRx 3 = paclobutrazol (Bonzi) applied three times; Br = Brushed; LW = Low watering; HW = High watering.

**Figure 43. Impatiens – Plant height after storage at 20ºC for 48 hours.**




**Key:** Poly = Polytunnel i.e. no storage; Con = No treatment; Cool = Grown at 2ºC cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 paclobutrazol (Bonzi) applied once; GRx2 = paclobutrazol (Bonzi) applied twice; GRx 3 = paclobutrazol (Bonzi) applied three times; Br = Brushed; LW = Low watering; HW = High watering.

**Table 8. Impatiens – Mean scores for crop uniformity and size before and after storage, and the relative difference in the scores. (Bold represents large changes).**

| Treatment | Uniformity | | | Size | | |
|---|---|---|---|---|---|---|
| | Before | After | *Diff* | Before | After | *Diff* |
| Poly | 2.5 | 2.5 | *0.0* | 2.6 | 2.5 | *-0.1* |
| Con | 2.7 | 2.7 | *0.0* | 2.8 | 2.9 | *0.1* |
| Cool | 2.8 | 2.8 | *0.0* | 2.7 | 3.0 | *0.3* |
| CaCl | 2.5 | 2.3 | *-0.2* | 1.6 | 1.4 | *-0.2* |
| KCl | 2.0 | 2.2 | *0.2* | 1.2 | 1.2 | *0.0* |
| PO3 | 2.1 | 2.4 | *0.3* | 1.7 | 1.7 | *0.0* |
| GRx1 | 2.2 | 2.3 | *0.1* | 2.6 | 2.7 | *0.1* |
| GRx2 | 2.6 | 2.6 | *0.0* | 2.8 | 2.8 | *0.0* |
| GRx3 | 2.8 | 2.8 | *0.1* | 1.3 | 1.5 | *0.2* |
| Br | 2.2 | 2.4 | *0.2* | 2.5 | 2.3 | *-0.2* |
| LW | 2.7 | 2.6 | *-0.1* | 1.8 | 2.1 | *0.3* |
| HW | 2.5 | 2.4 | *-0.1* | 2.3 | 1.6 | ***-0.7*** |
| LSD | 0.17 | 0.17 | | 0.23 | 0.23 | |

**Key:** Poly = Polytunnel i.e. no storage; Con = No treatment; Cool = Grown at 2ºC cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 = paclobutrazol (Bonzi) applied once; GRx2 = paclobutrazol (Bonzi) applied twice; GRx 3 = paclobutrazol (Bonzi) applied three times; Br = Brushed; LW = Low watering; HW = High watering.

**Table 9 Impatiens – Mean scores for crop habit and flower development before and after storage, and the relative difference in the scores. (Bold represents large changes).**

| Treatment | Habit | | | Flower Development | | |
|---|---|---|---|---|---|---|
| | Before | After | *Diff* | Before | After | *Diff* |
| Poly | 2.5 | 2.3 | *-0.2* | 2.6 | 2.7 | *0.1* |
| Con | 2.8 | 2.6 | *-0.2* | 2.9 | 2.9 | *0.0* |
| Cool | 2.8 | 2.8 | *0.0* | 2.9 | 2.8 | *-0.1* |
| CaCl | 2.1 | 2.0 | *-0.1* | 2.7 | 2.8 | *0.1* |
| KCl | 1.7 | 1.8 | *0.1* | 2.8 | 2.6 | *-0.2* |
| PO3 | 2.1 | 2.0 | *-0.1* | 2.7 | 2.6 | *-0.1* |
| GRx1 | 2.3 | 2.3 | *0.0* | 2.8 | 2.7 | *-0.1* |
| GRx2 | 2.7 | 2.5 | *-0.2* | 2.9 | 2.5 | ***-0.4*** |
| GRx3 | 2.0 | 2.0 | *0.0* | 2.7 | 2.9 | *0.2* |
| Br | 2.3 | 2.2 | *-0.1* | 2.9 | 2.7 | *-0.2* |
| LW | 2.2 | 2.4 | *0.2* | 3.0 | 2.9 | *0.1* |
| HW | 2.3 | 1.8 | ***-0.5*** | 2.7 | 2.2 | ***-0.5*** |
| LSD | 0.18 | 0.17 | | 0.15 | 0.19 | |

**Key:** Poly = Polytunnel i.e. no storage; Con = No treatment; Cool = Grown at 2ºC cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 = paclobutrazol (Bonzi) applied once; GRx2 = paclobutrazol (Bonzi) applied twice; GRx 3 = paclobutrazol (Bonzi) applied three times; Br = Brushed; LW = Low watering; HW = High watering.

**Pelargonium**

In the period prior to storage, highest plant quality scores were associated with Cool, GRx1, Brushed and Low watering treatments (Figure 44). These plants tended to have a relatively good habit and for the most part a compact stature (Tables 10 and 11). Plants exposed to the more frequent growth regulator application tended to be very compact and undersized. They also possessed leaves of a darker purple-green hue, with more discoloration of older leaves which resulted in some assessors indicating a leaf injury (Figure 45).

Plants in the Cool and Brushed treatments tended to retain their overall quality (Plate 3), whereas there was some loss of quality recorded in the GRx1 and Low watered treatments after storage (Figure 44). The Low watered plants were still one of the most compact treatments (Figure 46), but the plants within the trays were slightly less uniform after storage. (Table 10). There was almost no new growth apparent in the plants treated more frequently with growth regulator (GRx2 and GRx3), but again plants in these treatments were becoming more conspicuous by their deep dark green leaves and tightly held small flower buds (Photo 4).

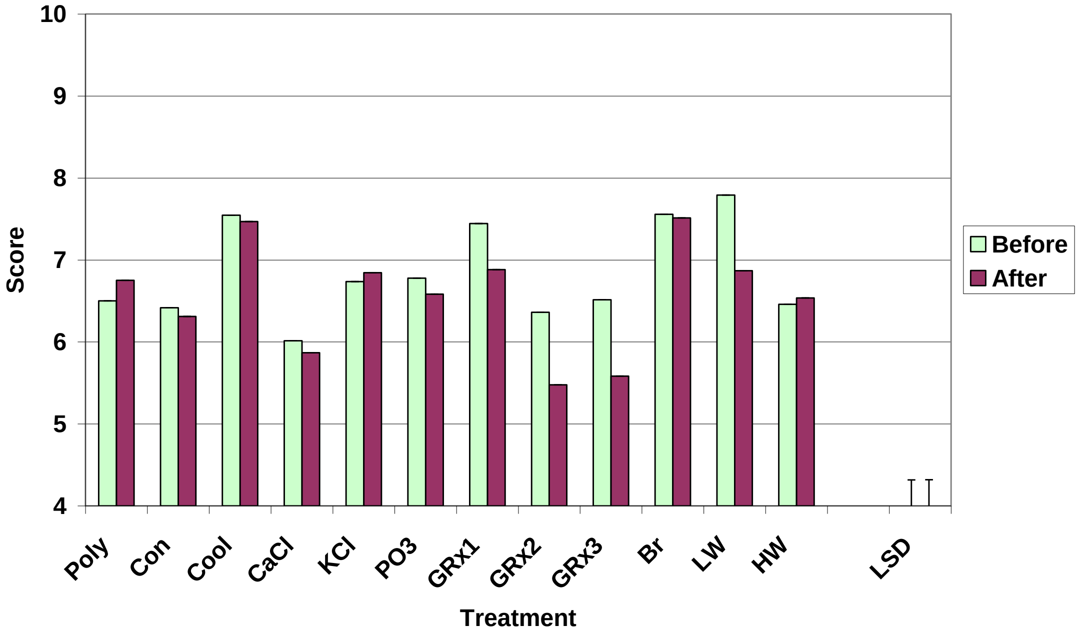
Plants in the High watering treatment and those plants exposed to CaCl, KCl and PO3 treatments all grew the largest. This tended to result in some loss of uniformity, but often the plant habit itself was acceptable.

At the time of storage, the Pelargonium crop was just at the stage when the flower stalks were beginning to extend, so there were no scores for flower development or health.

*Potential applications* – Cool grown, Brushed.

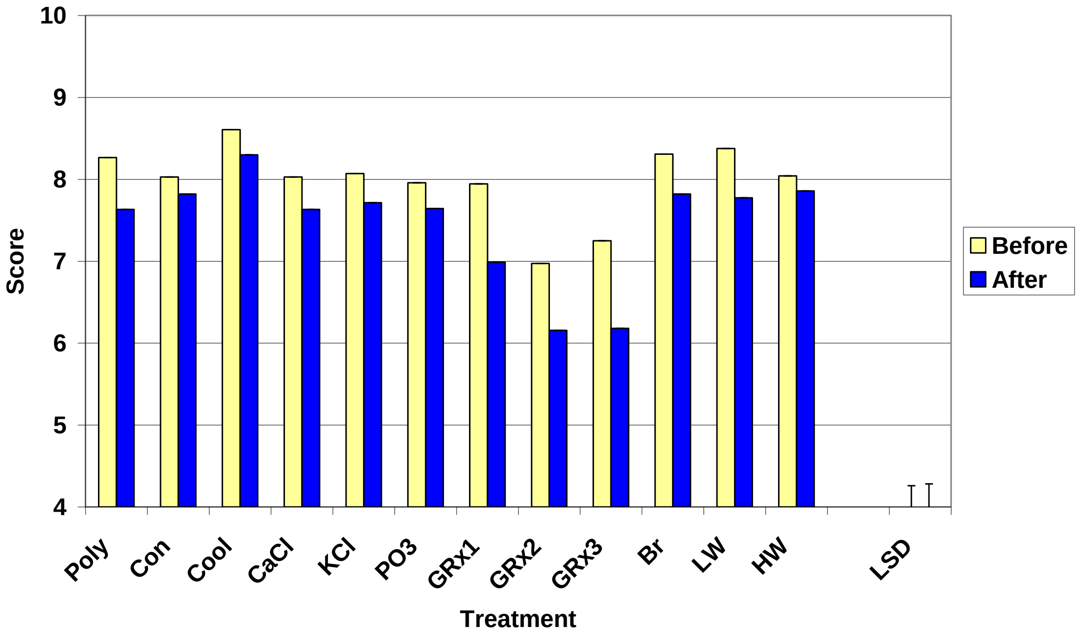
**Figure 44. Pelargonium – Quality score before and after storage at 20ºC for 48 hours.**




**Key:** Poly = Polytunnel i.e. no storage; Con = No treatment; Cool = Grown at 2°C cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 = paclobutrazol (Bonzi) applied once; GRx2 = paclobutrazol (Bonzi) applied twice; GRx 3 = paclobutrazol (Bonzi) applied three times; Br = Brushed; LW = Low watering; HW = High watering.

**Figure 45. Pelargonium – Leaf 'health' score before and after storage at 20°C for 48 hours.**

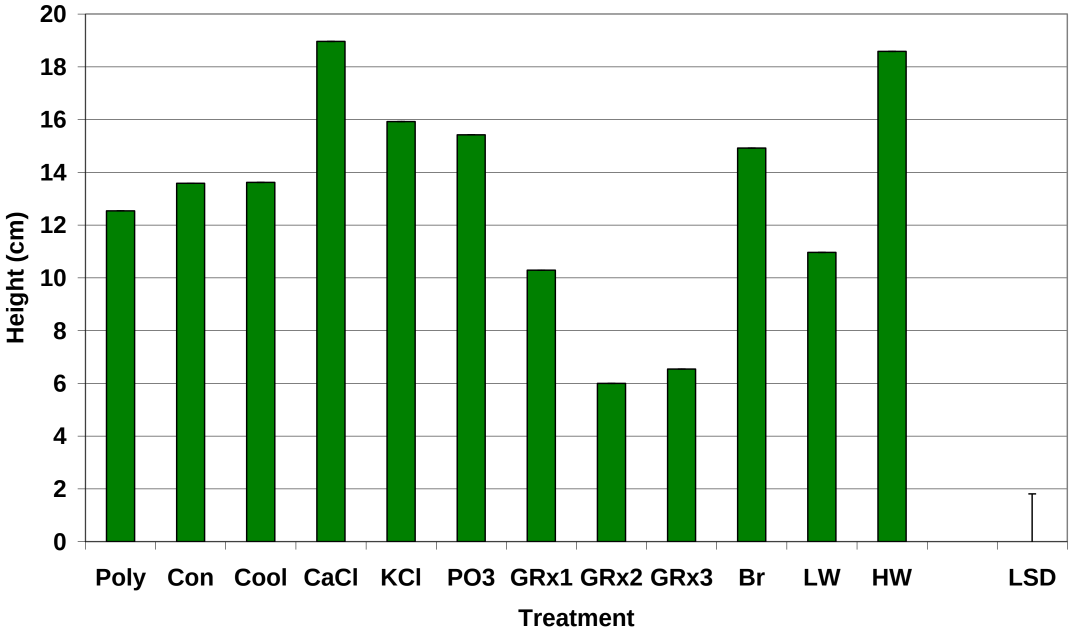



**Key:** Poly = Polytunnel i.e. no storage; Con = No treatment; Cool = Grown at 2°C cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 = paclobutrazol (Bonzi) applied once; GRx2 = paclobutrazol (Bonzi) applied twice; GRx 3 = paclobutrazol (Bonzi) applied three times; Br = Brushed; LW = Low watering; HW = High watering.

**Plate 3. Pelargonium – Brushing treatment resulted in a relatively uniform tray with a relatively good plant size and habit.**


**Plate 4. Pelargonium - The application of Growth Regulators at 2 or 3 separate applications maintained a compact habit, but caused some leaf discoloration and flower stalks did not emerge above the leaf canopy.**

**Figure 46. Pelargonium – Plant height after storage at 20$^{o}$C for 48 hours.**




**Key:** Poly = Polytunnel i.e. no storage; Con = No treatment; Cool = Grown at 3°C cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 = paclobutrazol (Bonzi) applied once; GRx2= paclobutrazol (Bonzi) applied twice; GRx 3 = paclobutrazol (Bonzi) applied three times; Br = Brushed; LW = Low

**Table 10. Pelargonium – Mean scores for crop uniformity and size before and after storage, and the relative difference in the scores.**

| Treatment | Uniformity | | | Size | | |
|---|---|---|---|---|---|---|
| | Before | After | *Diff* | Before | After | *Diff* |
| Poly | 1.9 | 2.0 | *0.1* | 2.6 | 2.5 | *0.0* |
| Con | 1.9 | 2.0 | *0.1* | 2.4 | 2.2 | *-0.2* |
| Cool | 2.5 | 2.5 | *0.0* | 2.1 | 2.1 | *0.0* |
| CaCl | 1.9 | 2.0 | *0.1* | 1.1 | 1.1 | *0.0* |
| KCl | 1.9 | 2.1 | *0.2* | 1.6 | 1.8 | *0.2* |
| PO3 | 2.1 | 2.0 | *-0.1* | 1.6 | 1.7 | *0.1* |
| GRx1 | 2.6 | 2.6 | *0.0* | 2.8 | 2.7 | *-0.1* |
| GRx2 | 2.9 | 2.8 | *-0.1* | 1.6 | 1.5 | *-0.1* |
| GRx3 | 2.8 | 2.8 | *0.0* | 1.6 | 1.5 | *-0.1* |
| Br | 2.4 | 2.6 | *0.2* | 1.9 | 2.0 | *1.0* |
| LW | 2.5 | 2.3 | *-0.2* | 2.7 | 2.5 | *-0.2* |
| HW | 2.1 | 2.2 | *0.2* | 1.0 | 1.1 | *0.1* |
| LSD | 0.20 | 0.17 | | 0.25 | 0.25 | |

**Key:** Poly = Polytunnel i.e. no storage; Con = No treatment; Cool = Grown at 3°C cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 = paclobutrazol (Bonzi) applied once; GRx2 = paclobutrazol (Bonzi) applied twice; GRx 3 = paclobutrazol (Bonzi) applied three times; Br = Brushed; LW = Low watering; HW = High watering.

**Table 11. Pelargonium – Mean scores for crop habit and flower development before and after storage, and the relative difference in the scores.**

| Treatment | | Habit | |
|---|---|---|---|
| | Before | After | *Diff* |
| Poly | 2.2 | 2.2 | *0.0* |
| Con | 1.9 | 1.9 | *0.0* |
| Cool | 2.5 | 2.4 | *-0.1* |
| CaCl | 1.6 | 1.7 | *0.1* |
| KCl | 1.8 | 2.1 | *0.3* |
| PO3 | 1.9 | 2.0 | *1.0* |
| GRx1 | 2.5 | 2.3 | *-0.2* |
| GRx2 | 1.8 | 1.8 | *0.0* |
| GRx3 | 1.9 | 1.8 | *-0.1* |
| Br | 2.3 | 2.5 | *0.2* |
| LW | 2.5 | 2.3 | *-0.2* |
| HW | 1.7 | 2.0 | *0.3* |
| LSD | 0.20 | 0.19 | |

**Key:** Poly = Polytunnel i.e. no storage; Con = No treatment; Cool = Grown at 3°C cooler than other treatments; CaCl = Calcium chloride treatment; KCl = Potassium chloride treatment; PO3 = Potassium phosphite treatment; GRx1 = paclobutrazol (Bonzi) applied once; GRx2 = paclobutrazol (Bonzi) applied twice; GRx 3 = paclobutrazol (Bonzi) applied three times; Br = Brushed; LW = Low watering; HW = High watering.

## Conclusions

Bedding plants can be rejected at the point of delivery due to factors associated with their transport or their management shortly before loading (e.g. over-watering and under-watering). The researchers found examples of plants both badly wilted on arrival at their destination or delivered with the foliage and petals saturated with water droplets. These were rare exceptions and the vast majority of crops observed arrived in good quality.

It was evident from data collected in Year 1 that both refrigerated and non-refrigerated wagons were commonly used to transport bedding plants. When a nursery considered ambient conditions were suitable, non-refrigerated wagons could be used, or on some occasions wagons with chilling facilities, but with the chiller unit switched off. The vast majority of transport runs were carried out at temperatures between 11ºC and 16ºC, although some summer runs were recorded at 18-21ºC. This included a run where the driver set the temperature control to 12ºC, but considered temperatures of 15-16ºC to be maintained, whereas in fact the data recorder actually logged temperatures of 21ºC. This corresponds to the findings of Høyer (1997a) where recorded temperatures in the wagon could vary significantly compared to the set-point value.

### Temperature and duration of storage

Extremes of temperature were noted during some transit runs. For example, 4.8ºC was recorded in a crop in late November (crop type unknown) and 33ºC for a summer run. Lower temperatures (2.7ºC) were also recorded in a refrigerated wagon in May 2006, but it was believed that by that point all crop plants had been removed. High (22ºC) and low (12ºC) temperatures were used for comparisons of wagon environments in controlled experiments in Year 2 of the project. Interestingly, loss of quality could be recorded at these temperatures, especially at longer durations (see below), and this is a cause for concern as these were still some way short of the extreme temperatures recorded (albeit rarely) in real transport situations.

Length of storage was a key factor in determining injury and warmer temperatures combined with prolonged durations, in general, resulted in the greatest loss of quality. Data from Year 2 showed that most injuries and 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. See Table 12, for a summary of species responses. Similar responses have been reported recently for Diascia (Beach, 2005). 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 and have been attributed to this in previous studies (Armitage, 1993), 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. These results are significant, as long duration transport runs were observed in Year 1, although again they were in the minority compared to short runs less than 24 hours.

Data from Year 2 demonstrated that loss of quality can be evident even after 24 hours. For example, Petunia lost quality after only 24 hours, with poor plant size and habit scores being recorded. Flower quality also deteriorated when the crop was wet, or placed in storage at high humidity even at the 24 hour durations (both at 12ºC and 22ºC). These are realistic scenarios for many commercial transport movements, especially when growers load up the crop into the wagon the night before departure.

More common than extremes of absolute temperature found in commerce were the rapid transitions of temperature and humidity bedding plants were exposed to. They could be stored in a lorry wagon in the dark at 11ºC one moment, then a short time later be placed directly in strong sunlight at 35ºC. In contrast to the data on duration, there was little evidence that rapidly moving plants from cool dark conditions to bright sunlight and high temperatures was damaging. In most cases well-watered plants were undamaged when moved from low to higher temperatures, or from dark to light. However, over the latter course of the project, periods of consistently high natural temperatures and high irradiance levels were not encountered, so it was difficult to verify some of these conclusions with respect to very hot summer days and high levels of sunlight (e.g. the maximum temperature outside in these controlled experiments was 29ºC).

**Table 12. 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 and 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

**Temperature of the growing medium**

Growers were keen to understand whether loss of plant quality might relate to root dysfunction during the transport period, and particularly, the temperature regimes that roots may experience in practice once they had left the nursery. Roots are generally more susceptible to extremes of temperatures than shoots and it was important to categorise the range of temperatures they may experience in transit. Data from Year 1 showed that for the most part root temperature tended to be very similar to the air temperatures the crop was experiencing. There were a few occasions, however, where variations between air and media readings occurred suggesting that irrigation events had taken place (rapid drops in media temperature) or the plants had been moved to a warm environment, but that roots were buffered against the rapid transitions (slow rise in root temperature, compared to rapid rise in air). There was no evidence that roots were experiencing directly damaging temperatures, nor that root injury was a primary cause of quality loss.

**Humidity**

Relative humidity was frequently high (>95%) for part or all of the run period, in the majority of transits recorded. High r.h. was recorded at the lower transport temperatures and also at many of the warmer ones too, especially when the wagon had a full load. In the longest run recorded, crops were held in the dark for over 42 hours at approx. 95 % r.h. and 15ºC. One of the most interesting aspects of the project was that high humidity had a negative effect on crop quality. Experiments involving Petunia and Impatiens, showed that high humidity levels in the cabinets resulted in reduced plant quality, especially over longer duration storage periods of 48 hours. Symptoms included yellowing of new leaves and rolling or wilting of the older leaves. Some of the symptoms were temporary, disappearing after a further 48 hours in the polytunnel, but were notable enough immediately after storage, to probably result in a crop rejection. In addition to leaf effects, Petunia flowers often possessed a flaccid, wilted appearance on removal from high humidity environments, regardless of storage temperature.

Although high humidity has been accredited with being detrimental to some crops during production (Hendriks, 2001; Fjeld, 1986), the data from this project is relatively novel in that, not only was it clearly evident that crop exposure to high humidity was commonplace during transportation, but that some crops such as Petunia were sensitive to it over relatively short time spans.

**Wet foliage and flowers**

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 2). Flowers were often more prone to injury than foliage, e.g. Petunia, Cyclamen and Pansy all showed some flower damage when stored wet.

**Watering**

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'.

Growers recognise the importance of appropriate irrigation regimes during the production phase to determine final plant quality. Results in this project confirm that a good quality crop can be obtained through careful regulation of water inputs during the production phase. In this case, plants were kept compact by maintaining a total tray weight (6 cell and peat:bark medium) of between 750 and 900 g. Some species are more amenable to these drier regimes (e.g. Pelargonium) than others (e.g. Impatiens). Conversely, crop quality was often compromised by the high watering regimes employed.

Keeping plants on a low watering regimes is probably one of the most practical techniques growers can employ to maintain quality. Plants maintained on a low watering regime during production in Year 3 (350-500 g per tray) proved to be relatively robust in terms of keeping their size and habit during the subsequent transport phase. This treatment helped minimise shoot extension during storage in two out of the three species (Petunia and Impatiens), but was less effective at 'holding-back' growth in storage with Pelargonium.

*NB - AT NO TIME SHOULD THE DRY REGIME BE CONTINUED INTO THE STORAGE PHASE ITSELF – PLANT MEDIA WILL NEED TO BE WELL WATERED AND WETTED UP THOROUGHLY BEFORE TRANSPORTATION.*

**Ethylene**

Information gained from the literature suggested that some crops may be sensitive to ethylene during transit. However, the degree of injury depends strongly on cultivar, exposure time, temperature and even carbon dioxide levels. Levels of ethylene recorded in bedding crops in this project were in the range of 1-2.5 ppm, (the higher levels according to the literature being potentially injurious if exposure times were prolonged). For example, *Impatiens x hawkeri* cv. Sunfire was shown to have 80-100% flower abscission after only 4 hours exposure to 1 ppm ethylene (Dostal *et. al.,* 1991). There was, however, no direct evidence of injury in any crops inspected in the hubs during this project.

The peaks in ethylene data correlating with the decaying Christmas trees and, to a lesser extent the activity of the mechanical floor sweeper, are potential causes for concern. It does highlight that both growers and retailers need to be careful to avoid external sources of ethylene having a detrimental impact on the crop. This also includes residual doses of ethylene associated with a previous cargo that has been shipped in the lorries used for bedding. (Ethylene can remain absorbed onto the walls and other hard surfaces).

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 22$^{o}$C. 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 12$^{o}$C. There was also a limited amount of leaf yellowing and *Botrytis* associated with plants stored in boxes at 22$^{o}$C. *Botrytis* was also problematic in this crop in Experiment 1, especially when plants were held wet at 12$^{o}$C for prolonged periods, and this aspect may merit further investigation.

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 than storage duration.

**Pre-conditioning (Toning) treatments**

A number of management techniques appeared to have potential for improving crop performance during the transport process. As outlined above, using irrigation as a tool to minimise excessive extension growth during production, also appeared to have promise in providing a residual effect during transportation. Compact plants often maintained their compactness during storage, despite being well-watered prior to shipping itself (Note limited change in quality scores in the Low watering regimes in Figures 39 and 42).

The most consistent treatment across the three species in promoting good plant quality *and maintaining* it during storage was the Cool treatment. We used a fan-ventilated glasshouse to maintain temperatures at approximately 2ºC cooler than our main experimental glasshouse. Forced fan-ventilation is highly unlikely to be a cost-effective option for growers, but the experiment points out the need for optimising roof and side panel ventilation, and where possible attempting to grow the crop at cooler temperatures, especially at the stage immediately prior to marketing, in an attempt to keep the crop compact. These results with lower watering and cooler growing regimes confirm observations by Armitage (1986; 1993), who also considered them to be effective pre-conditioning tools.

A single application of a growth regulator approximately 4-5 days before storage also appeared to be a positive strategy, as there was some evidence that it had a residual effect of holding back growth during transit. This was most evident in the Pelargonium. Similarly, the Brushing treatment was deemed successful with Pelargonium. This did not produce the shortest plants by the time of the assessments, but the crop was considered to have a good habit and be uniform in appearance. There were some very marked appearances though with this treatment during the earlier stages of production (data not shown), where the crop was 30-50% shorter than controls. Brushing in this instance was very labour intensive and not commercially feasible. However, there may be other strategies to induce the thigmomorphogenetic responses (Garner and Langton, 1997).

Repeated use of growth regulators (i.e. GRx2 and GRx3) resulted in plants that were often scored low by the assessors. There were three main reasons for this:
1/ the application seemed to result in non-uniform growth (some plants more stunted than others within the tray).
2/ The plants often had non-typical growth patterns (including limited evidence they would ‘grow away’ from these).
3/ The short stature or delayed nature of the growth habit meant that they would score low in assessments relating to flower number or extent of canopy cover over the tray.

One of the most interesting results was the growth promotion associated with increasing the electrical conductivity of the media via mineral addition, rather than a shortening of stem growth. This maybe explained by the nutrition balance of the crop as the KCl and the $KPO_3$, were providing extra potassium (and in the case of $KPO_3$, nitrogen was also included in the formulation). More of a puzzle is why CaCl should enhance growth – it being relatively unlikely Ca was a limitation to growth potential, as the tapwater used for irrigation is pH 7 and contains high levels of calcium carbonate.

Further work may be warranted on the use of chemical ionic compounds to regulate growth. The rates applied in this project may well have been sub-optimal to induce a growth reduction response, especially as some of the ions may have been washed out with routine irrigation procedures applied between treatment dates. Unfortunately, there was not sufficient time to test a range of different concentrations of each chemical prior to the onset of the pre-conditioning experiment, and application rates were based on information from the literature only.

**Overview**

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 12$^{o}$C storage in Cyclamen may be less well recognised. Good husbandry during the production phase (growing the crop drier or cooler, and possibly using a single growth regulator application a few days before transport) will help offset problems later on during transportation, but even high quality crops can deteriorate quickly if environmental stresses become excessive (long periods of high temperature, darkness, high humidity or ethylene). Growers need to recognise the limitations in the distribution process itself especially in relation to long-distance journeys, or prolonged handling procedures, (long periods in dispatch / hubs etc.) but practical elements growers may wish to consider (if they have not already done so) include the use of cool chain transport, reducing leaf wetting during transit and adopting feasible pre-conditioning techniques such as regulating growth via irrigation or chemical means.

**Technology Transfer**

Information from the project has been disseminated through the following conferences and articles:

- HDC / BBPA AGM and Grower Conference (New Crops and New Technologies, Oxford, 8th Feb 2007)
- HDC / BPOA / BOPP Technical Seminar, Hellidon, 26th June 2008.
- HDC News 130 (Feb 2007). Long Haul – First Class.
- HDC News 140 (Feb 2008). Avoiding Transport Trauma

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**References**

Al-Saqri, F.A., Barrett, J.E., Bartuska, C.A., Clark, D.G. and Schoellhorn, R.K. (2003). Shipping and ethylene effects on flower bud abscission in potted *Hibiscus rosa-sinensis*. Acta Horticulturae, 628: 303-310.

Anon (2002) DEFRA Basic Horticultural Statistics for the United Kingdom - Calendar and crop years 1991/92-2001/02. http://statistics.defra.gov.uk/esg/publications/bhs/2004

Armitage, A.M. (1986). Influence of production practices on post-production life of bedding plants. Acta Horticulturae, 181: 269-277.

Armitage, A.M. (1993). Bedding plants-prolonging shelf performance- Postproduction care and handling. Batavia, Illinois, Ball Publishing, 71pp.

Beach, S.H. (2005). Shipping and nitrogen toning effects on post-harvest shelf-life of vegetative annuals. MSc Thesis. Texas A&M University.

Blanchard, M.G., Newton, L.A., Runkle, E.S., Woolard, D. and Campbell, C.A. (2007). Exogenous applications of abscisic acid improved the postharvest drought tolerance of several annual bedding plants. Acta Horticulturae, 755:127-133

Borch, K., Brown, K.M. and Lynch, J.P.(1998). Improving bedding plant quality and stress resistance with low phosphorus. Hortechnology, 8: 575-578.

Borch, K., Miller, C., Brown, K.M. and Lynch, J.P. (2003). Improved drought tolerance in marigold by manipulation of root growth with buffered phosphorus nutrition. Hortscience, 38: 212-216.

Borch, K., Williams, M. H. and Høyer, L. (1996). Influence of simulated transport on postharvest longevity of three cultivars of miniature potted rose. Acta Horticulturae, 424: 175-180.

Broschat, T.K. (2006). Effects of phosphorous and phosphoric acids on growth and phosphorus concentrations in container-grown tropical ornamental plants. HortTechnology 16: 105-8.

Bulle, A.A.E., Slootweg, G. and Vonk, N.C. (2000). Effects of vibration during transport on the quality of pot plants. Acta Horticulturae, 518: 193-199.

Chantry, N. (2007). Sub-strategy for liner production. Horticultural Development Company Hardy Nursery Stock Research and Development Strategy. http://www.hdc.org.uk/sectors/HNS%20RandD%20SS%20Growth%20Regulation%20Strategy.pdf

Custódia, M.L.G., Monteiro, J.A. and Rodrigues, M.H. (2001). Bougainvillea post-production: NAA and STS control of bract abscission is subject to exogenous ethylene. Acta Horticulturae, 543: 47-53.

Dijk, A. van and Barendse, H. (1991). Determining keeping quality of pot plants. Acta Horticulturae, 298: 267-273.

Dostal, D.L., Agnew, N.H., Gladon, R.J. and Weigle, J.L. (1991). Ethylene, simulated shipping, STS and AOA affect corolla abscission of New Guinea impatiens. HortScience. 26: 47-49.

Druege, U. (2001). Postharvest responses of different ornamental products to preharvest nitrogen supply: Role of carbohydrates, photosynthesis and plant hormones. Acta Horticulturae, 543: 97-105.

Edmondson, R. and Parsons, N. (2005). Objective criteria for the standardisation and improvement of bedding plant production. 1st Annual Report, PC-200. Horticultural Development Council.

Fjeld, T. (1986). The effect of relative humidity, light intensity and temperature on keeping quality of *Begonia* x *cheimantha* Everett. Acta Horticulturae, 181: 251-256.

Hartley, G., Nell, T.A., Leonard, R.T., Barrett, J.E. and Boyle T.H.. (1995). Effect of interior light and temperature on longevity of *Rhipsalidopsis*. Acta Horticulturae, 405: 164-169.

Hell, B. ter and Hendriks, L. (1995). The influence of nitrogen nutrition on keeping quality of pot plants. Acta Horticulturae, 405: 138-147.

Hendriks, L. (2001). Cultural factors affecting post-harvest quality of potted plants. Acta Horticulturae, 543: 87-96.

 

Høyer, L. (1984). Elatior begonia cv. Sirene: Keeping quality adversely affected by exposure to ethylene and poor light conditions. Gartner Tidende 100: 1170-1171.

Høyer, L. (1986). Silver thiosulphate can to some extent prevent leaf, bud and flower drop in *Hibiscus rosa-sinensis* caused by ethylene and darkness. Acta Horticulturae, 181: 147-154.

Høyer, L. (1989). Ethylene concentrations during transport of pot plants. Acta Horticulturae, 261: 359-365.

Høyer, L. (1995). Investigations of the ethylene build-up during transport of pot plants in controlled temperature trucks. Postharvest Biology and Technology, 5: 101-108.

Høyer, L. (1996). Critical ethylene exposure for *Capsicum annuum* 'Janne' is dependant on an interaction between concentration, duration and developmental stage. Journal of Horticultural Science, 71: 621-628.

Høyer, L. (1997a). Investigations of product temperature management during transport of pot plants in controlled temperature trucks. Gartenbauwissenschaft, 62: 50-55.

Høyer, L. (1997b). Critical ethylene exposure for *Hibiscus rosa-sinensis* is dependent on an interaction between ethylene concentration and duration. Postharvest Biology and Technology, 9: 87-95.

Høyer, L. (1998a). Silver thiosulphate can considerably reduce leaf and fruit abscission caused by ethylene in *Capsicum annuum* 'Janne'. Journal of Horticultural Science and Biotechnology, 73: 29-34.

Høyer, L. (1998b). The effects of relative air humidity on postproduction quality. In the proceedings of workshop on 'The influence of cultivation conditions on the keeping quality of ornamentals' FYN Denmark.1998.

Høyer, L., Borch, K. and Williams, M.H. (1996). Post production quality of pot roses: a result of interaction between cultivar, post-production conditions and numbers of open flowers at the time of sale. Acta Horticulturae, 424: 191-193.

Høyer, L. and Kristensen, K. (1991). Low post-harvest temperature reduce the collapsing of *Primula vulgaris* 'Dania Skarlagen'. Acta Horticulturae, 298: 287-295.

Garner, L.C. and Langton, F.A. Brushing pansy (*Viola tricolor* L.) transplants: A flexible, effective method for controlling plant size. Scientia Horticulturae, 70, 187-195.

Gehring, T.M. and Lewis, A.J. (1980). Extending the shelf life of bedding plants. III. Antitranspirants. Florists Review, 165: 65.

Geoffroy, D. and Vial, F. (2004). Distribution routes and quality of pot plants: cyclamen sets the tone. PHM Revue Horticole., Perols, France. 460: 37-41.

Kays, S.J., Jaworski, C.A. and Price, H.C. (1976). Defoliation of pepper transplants in transit by endogenously-evolved ethylene. Journal of the American Society for Horticultural Science, 101: 449-451.

Klock-Moore, K.A. (2001). Postproduction performance of *Imaptiens* plants grown in substrates containing compost. Acta Horticulturae: 543: 127-133.

Labouriau, R. and Høyer, L. (2001). Temperature dependence of ethylene induced leaflet abscission in *Radermachera sinica.* Acta Horticulturae, 543: 79-82.

Langton, A., Edmondson, Parson, N. (2002). Horticulture LINK project HL0134LPC Robust product design and prediction for post-harvest pot-plant quality and longevity.

Leonard, R.T., Nell, T.A. and Barrett, J.E. (1995). Effects of production and postproduction factors on longevity and quality of potted carnations. Acta Horticulturae, 405: 356-361

Leonard, R.T. and Nell, T.A. (2000). Effects of production and postproduction factors on longevity and quality of kalanchoe. Acta Horticulturae, 518: 121-124.

Leonard, R.T.; Nell, T.A. and Høyer, L. (2005). Response of potted rose varieties to short-term ethylene exposure. Acta Horticulturae, 669: 373-380.

Mayak, S. and Faragher, J. (1986). Storage environmental related stress and flower senescence. Acta Horticulturae, 181: 33–43.

Meeteren, U. van and van Gelder, H. (1995). Role of flower buds in flower bud abscission in *Hibiscus*. Acta Horticulturae, 405: 284-289.

 

Million, J.B., Barrett, J.E., Nell, T.A. and Clark, D.G. (2001). Late season applications of media surfactant improve water retention and time to wilt during postproduction. Acta Horticulturae, 543: 235-244.

Moe, R. and Smith-Eriksen, A. (1986). The effect of ethephon and STS treatment on flower malformation and flower bud abscission in *Begonia* x *cheimantha* Everett. Acta Horticulturae, 181: 155-160.

Mortensen, L.M. (1998). The influence of air humidity on growth and keeping quality of cut roses and some pots plants. In the proceedings of workshop on 'The influence of cultivation conditions on the keeping quality of ornamentals' FYN Denmark.1998.

Mulderij, G.E. (1991). Influence of postharvest light level on leaf drop and leaf necrosis of *Ficus benjamina* 'Starlight'. Acta Horticulturae, 298:153-160.

Muller, R., Sisler, E.C., Serek, M. (2000). Stress induced ethylene production, ethylene binding, and the response to the ethylene action inhibitor 1-MCP in miniature roses. Scientia Horticulturae, 83: 51-59.

Nell T. and Barrett J. (1990). Post-production handling of bedding and potted plants. Symposium on Bedding and Pot Plants (Ed. Heins, R). Acta Horticulturae, 272: 311-317.

Nell, T.A. and Noordegraaf, C.V. (1992). Postproduction performance of potted rose under simulated transport and low irradiance levels. HortScience, 27: 239-241.

Nell, T.A and Reid (2000). Flower and plant care – the 21st Century approach. Society of American Florists. www.ccfc.org/ccfc_media/retailers/media/pdf/care_manual.pdf.

Smith, T. (2001). Caring for Plants in the Retail Setting. University of Massachusetts Extension service leaflet. http://www.umass.edu/umext/floriculture/fact_sheets/business_management/retail.html

Snider, A., Palta, J.P., Peoples, T. (2003). Use of lysophosphatidylethanolamine (LPE), a natural lipid, to enhance opening and retention of flowers on bedding plants experiencing water stress during retail sales. Acta Horticulturae, 628: 849-853.

Shvarts, M., Weiss, D. and Borochov, A. (1997). Temperature effects on growth, pigmentation and longevity of petunia flowers. Scientia Horticulturae, 69: 217-227.

 

Song, C. and Lee, J. (1994). Effects of environmental conditions and growth regulators on flower bud abscission and flowering of potted camellia. Journal of the Korean Society for Horticultural Science, 35: 370-386.

Sterling, B. and Molenaar, P. (1986). The influence of time and temperature during simulated shipment on the quality of pot plants. Acta Horticulturae, 181: 429-434.

Williams, M. H., Andersen, L. and Høyer, L. (1995). Postproduction quality of potted patiohit® roses. Acta Horticulturae, 405: 33-38.

Willumsen, K. and Fjeld, T. (1995). The sensivity of some flowering potted plants to exogenous ethylene. Acta Horticulturae, 405: 362-371.

Woltering, E.J. (1986). Sensitivity of various foliage and flowering potted plants to ethylene. Acta Horticulturae, 181: 489-492.

Woltering, E.J. (1987). The effects of ethylene on ornamental plants: A classification. Scientia Horticulturae, 31: 283-294.

YounJung, K., ShinAe, P, HyeJin; B. and KiCheol, S. (2003). Effects of flowering stage, temperature, and vibration during simulated transport on the postproduction quality of potted *Kalanchoe blossfeldiana*. Korean Journal of Horticultural Science & Technology, 21: 369-374.