Project Title:	**HORTLINK - Robust Product Design and Prediction for Post-Harvest Pot Plant Quality and Longevity**
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CONTENTS

1. PRACTICAL SECTION FOR GROWERS / RETAILERS

1.1. Summary Overview at the end of Year 2

Poinsettia

- Simulated cold transport had a large, adverse effect on subsequent home life by increasing bract, leaf and cyathia loss.

- Low temperature (16ºC) gave higher home-life quality than high temperature (21ºC). It reduced cyathia loss and gave better bract colour.

- High light during home life (600 lux) reduced bract and leaf loss compared to low light (300 lux) but had little or no effect on cyathia loss or on bract colour.

- The home-life combination of low temperature and high light was particularly beneficial to poinsettia longevity.

- There was little or no effect on home-life quality of a heavy watering regime.

- Sonora scored higher for quality than Spotlight, and showed less bract and cyathia loss and better bract colour. Spotlight showed less leaf loss than Sonora.

- Objective quality scores were developed which related expert quality scores to measured physiological characters. Objective scores showed that the most important physiological characters affecting quality were bract drop, leaf drop, leaf colour, the proportion of abscised cyathia and bract edge necrosis.

- Chlorophyll fluorescence performance index (PI) gave similar trends to the expert quality scores during home life, indicating that this technique has the potential to show up batches of plants that have been stressed during marketing.

- Tissue mineral element levels were not affected by transport chain. However, levels of potassium, calcium and magnesium increased markedly from de-sleeving to the end of home-life. Plants at 21ºC had higher levels of all elements except nitrogen at the end of home-life than those at 16ºC.

Begonia

- Simulated cold transport had less effect on subsequent home-life quality in begonia than in poinsettia. However, cold transport and the commercial chain gave consistently lower flower counts than the minimum chain.

- Low temperature (16ºC) gave higher home-life quality than high temperature (21ºC) by reduced flower, coloured bud and green bud. Low temperature during home life also gave higher flower colour, foliar quality and foliar colour scores.

- High light (600 lux) during home life gave higher flower counts than low light (300 lux) by promoting bud opening. High light also slowed the decline in flower colour score and gave higher foliage quality and foliage colour scores.

- The home-life combination of low temperature and high light was particularly beneficial to begonia quality during home life.

- There was little obvious effect of a fluctuating watering treatment on home-life quality.

- Batik showed less coloured bud drop than Balli and gave higher total flower counts. There were no obvious differences in foliage quality or foliage colour.

- Objective quality scores indicated that the key physiological characters determining quality were flower and bud count, flower and bud drop, and leaf damage.

- The chlorophyll fluorescence PI index showed good potential as an indicator of plant stress during the marketing of begonia. However, middle-canopy leaves gave much higher readings than upper or lower canopy leaves and this will need to be taken into account in developing predictive tests.

- Effects of transport chain and home-life treatments on leaf mineral content were small. The only significant effect was a small rise in leaf manganese content in the fluctuating watering treatment at the end of home life.

1.2. Aims and Objectives

The aim of the project is to identify key production and supply chain factors affecting the robustness, longevity and quality of pot-plants during shelf and home-life. Improved production and transport regimes will ensure a more robust and better quality product for the marketplace. An essential part of the project is the development of objective statistical methods for measuring and monitoring quality, and methods will be based both on recorded physiological measurements and on chlorophyll fluorescence measurements.

Poinsettia and begonia were the model crops chosen for the project and, in years 1 and 2, the shelf and home-life quality of commercially grown plants were assessed following the use of a range of supply chains and simulated home-life environments. Objective statistical functions were developed to describe the effects of these environments on the physiological attributes of plant quality, and chlorophyll fluorescence screening techniques were tested as predictors of plant quality and longevity. The year 2 trials were essentially repeats of those in year 1 in order to confirm and extend the findings.

1.3. Treatments and Data

Batches of commercially-grown poinsettia and begonia plants (Double H Nurseries Ltd, New Milton, Hampshire) of each of two cultivars, Sonora and Spotlight for poinsettia (Plate 1) and Balli and Batik for begonia (Plate 4), were transported to HRI-Efford at the end of the first week of December (poinsettia) and during the first week of May (begonia).
Three levels of simulated supply chain stress were tested:

- *Minimum stress*: Pots transported directly to HRI-Efford with the minimum temperature above 14-15ºC.

- *Normal marketing*: Safeway chain for poinsettia and Sainsbury chain for begonia. Unfortunately the Safeway chain failed to deliver poinsettia plants to Efford and a new set of 'replacement' plants, analogous to minimum stress plants had to be substituted to ensure sufficient plant numbers for analysis of home-life treatment effects.

- *Simulated cold-transport stress*: Pots transported directly to HRI-Efford and then cold-stored at 7ºC (boxed) for 3 days

Simulated marketing was followed by 48 hours of simulated retail life at 18ºC and 1000 lux, followed by eight weeks (poinsettia) or 6 weeks (begonia) of simulated home-life treatments. The simulated home-life treatments were the various combinations of two contrasting temperatures (16ºC or 21ºC) given in separate rooms, two lighting levels for 14 hours/day (600 lux or 300 lux) and two watering regimes (standard or wet for poinsettia and standard or fluctuating for begonia). The wet regime for poinsettia was imposed by ensuring that there was always about 1 cm of water in the saucers in which plants were standing.

Physiological characters were measured weekly and an expert assessor from Double H Nurseries made weekly plant, bract, leaf and cyathium quality scores for poinsettia, and flower, foliar and overall plant quality scores for begonia. Chlorophyll fluorescence data

were collected throughout the course of both trials using equipment supplied by Hansatech Instruments Ltd., King's Lynn, UK. Parameters scored were Fv/Fm and a 'Performance Index' devised by Professor Strasser, consultant to the project. A 'double hit' assessment was also made whereby plants were scored a second time, immediately after the first, to test whether the additional machine-induced stress improved the level of discrimination between treatments.

1.4. Results

1.4.1. Poinsettia

As in year 1, simulated cold transport had a large, negative impact on subsequent plant quality (Plate 2). Bract loss during the first two weeks after de-sleeve was much greater in cold-transported plants than in minimum stress plants, and these effects are shown in Fig. A. Leaf loss was also exacerbated by cold transport, but effects were less marked than for bract loss. Cold transport also increased cyathia loss (in year 2 but not in year 1) and gave paler bracts. These physiological effects of cold transport were reflected in lower overall plant quality scores (as determined by 'expert' using a 1-10 scale) and, in general, cold transported plants were judged to be about one scale point lower than minimum stress plants throughout the 8 weeks of home life.

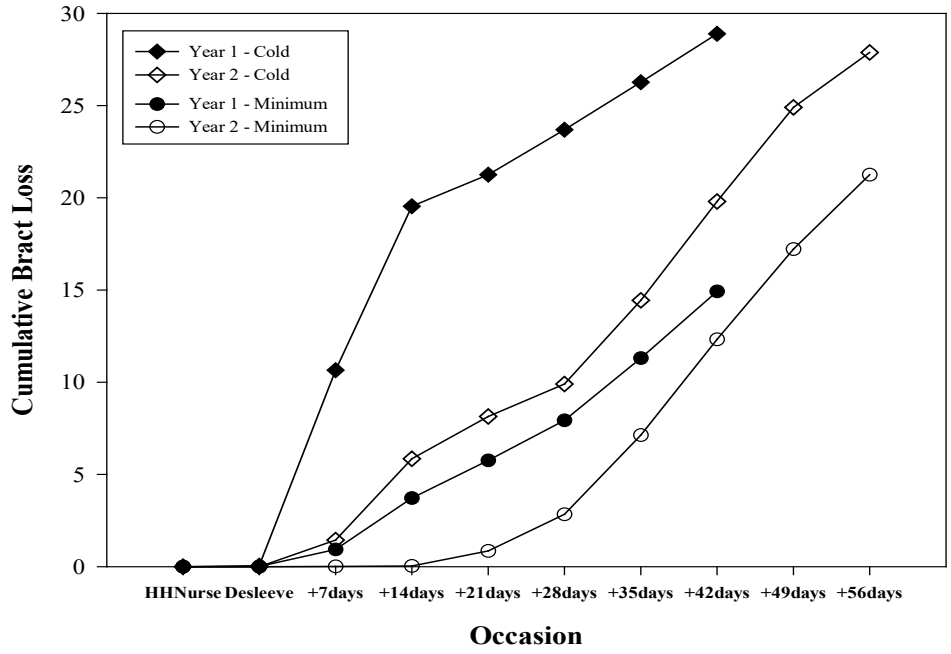

Fig. A. Effects of cold transport on cumulative bract loss in poinsettia

In year 1 the Sainsbury chain plants had tended to be either intermediate in quality between the cold-transported plants and the minimum stress plants, or similar to the cold-transported plants. This was probably because temperatures had been allowed to fall during delivery to the supply depot. It was not possible to judge the effects of the Safeway chain in year 2 since this chain failed (see earlier).

Interactions were shown in both years between transport chain and home-life temperature, making the effects of home-life temperature difficult to interpret. The most notable effect, however, was that cyathia loss was more rapid in both years at 21 ºC than at 16 ºC. Abscission started after 7 days of home-life in year 1 and after 14 days in year 2. Bract colour was also noticeably reduced by the higher temperature in year 2. Overall plant quality scores reflected the benefits of lower home-life temperature in minimum stress and Safeway plants, but not in cold-transported plants.

Plants receiving low light (300 lux) showed increased bract and leaf loss compared to plants at higher light (600 lux), and plant quality scores reflected the benefits of higher light after 21 days of home life. Light had little or no effect on cyathia loss or on bract colour and the effects of watering regime were rather small.

The home-life combination of low temperature and high light was particularly beneficial to poinsettia longevity (Plate 3).

Cultivar itself had large effects on perceived post-harvest quality and results were consistent between the years. Thus, Sonora showed less bract and cyathia loss than Spotlight and showed better bract colour. In contrast, Spotlight showed less leaf loss than Sonora. Overall plant quality scores showed Sonora to be of higher quality than Spotlight from day 7 of home life onwards.
Objective quality loss functions were developed mathematically as a two-stage process. First, expert scores were related to the measured physiological variates to give objective quality scores, and these scores were than modelled over time. Fig. B shows the decline in quality modelled in this way for two contrasting treatments.

This modelling phase indicated the key physiological factors determining expert plant quality scores in poinsettia, and factors affecting the rate of quality decline. Thus:

Sonora

- A lower proportion of cyathia on the plant reduced quality.
- The presence of pale leaves reduced quality.
- A significant interaction between cyathia proportion and the presence of pale leaves indicated that when pale leaves were present on the plant, a lower cyathia proportion improved quality, whereas if pale leaves were not present a lower cyathia proportion reduced quality.
- Bract drop reduced quality.
- The presence of bract edge necrosis (BEN) caused quality to be lowered.
- Pale bracts reduced quality.
- A significant interaction between pale bracts and BEN indicated that if BEN were present on the plant, then pale bracts had little effect on quality, whereas if BEN were not present, then pale bracts caused a lowering of quality.

- Cold-transport resulted in plants of lower quality than either the minimum stress chain or the ‘replacement’ chain.
- Quality was promoted by a home-life temperature of 16ºC.
- The rate of decline in plant quality was slower in cold-transported plants than in plants from either of the other two chains.

Spotlight

- A lower proportion of cyathia on the plant reduced quality.
- Bract drop reduced quality.
- Leaf drop reduced quality.
- The presence of BEN lowered quality.
- Pale leaves reduced quality.
- A significant interaction term indicated that the effect of pale leaves on plant quality was less marked when a plant had BEN than when it did not.

- Quality was enhanced when the home-life temperature was 16ºC.
- The rate of quality decline was greater in minimum stress plants than in plants from either of the other supply chains.
- The rate of quality decline was greater at 21ºC than at 16ºC.
- The rate of quality decline was greater at low light (300 lux) than at high light (600 lux).

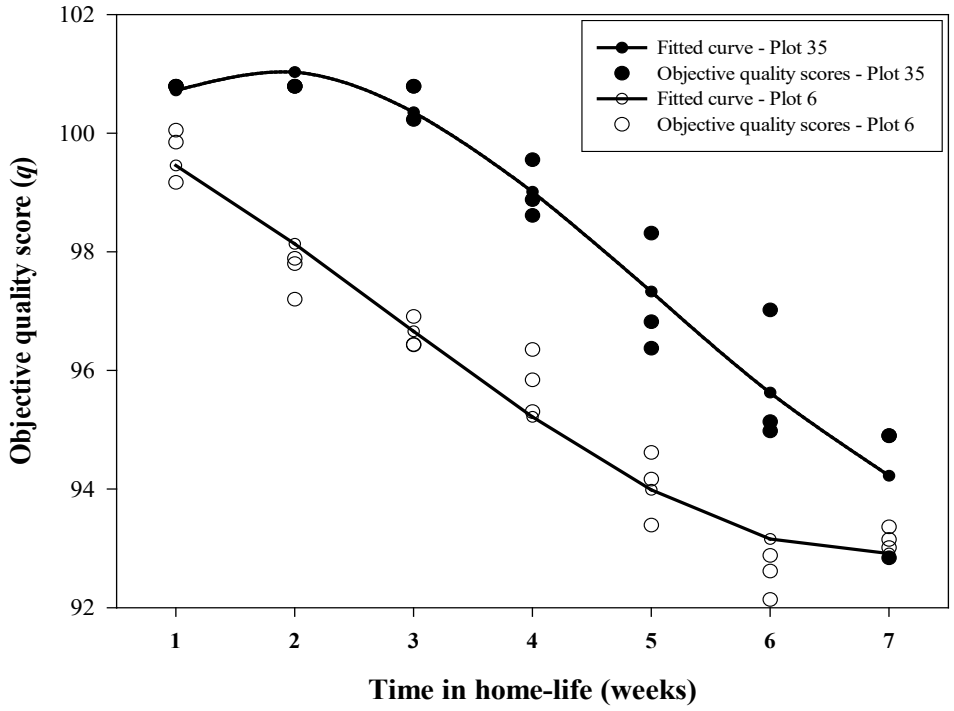

Fig. B. Modelled decline in quality during home life for poinsettia. Upper line: Sonora, minimum marketing stress, 16 ºC home-life temperature, 600 lux and standard watering; lower line: Spotlight, cold transport, 21 ºC home-life temperature, 300 lux and wet watering regime.

Chlorophyll fluorescence measurements made in year 2 appeared to be considerable more precise and sensitive to treatment effects than those made in year 1, presumably due to adjustments having been made to the measuring instruments. Fv/Fm ratio measurements showed that cold chain plants had a significantly reduced ratio at de-sleeving relative to the other two chains. During home life the ratio was reduced by the higher temperature treatment and was also strongly reduced by the low-light regime. The effect of the

watering regimes was slight but there was some suggestion of a reduced ratio from the wet regime. Spotlight gave a consistently lower ratio than Sonora throughout home life.

An alternative chlorophyll fluorescence score, the performance index (PI), showed a very different set of response curves in year 2 compared to year 1 and indicated much greater precision of measurement. The shape of the PI response curves for the various treatment regimes were very similar to the shape of the Fv/Fm response curves, but PI appeared to give better discrimination between plants from the cold-transport chain and plants from the other two chains at de-sleeving. Effects of transport chain on PI are shown in Fig. C.

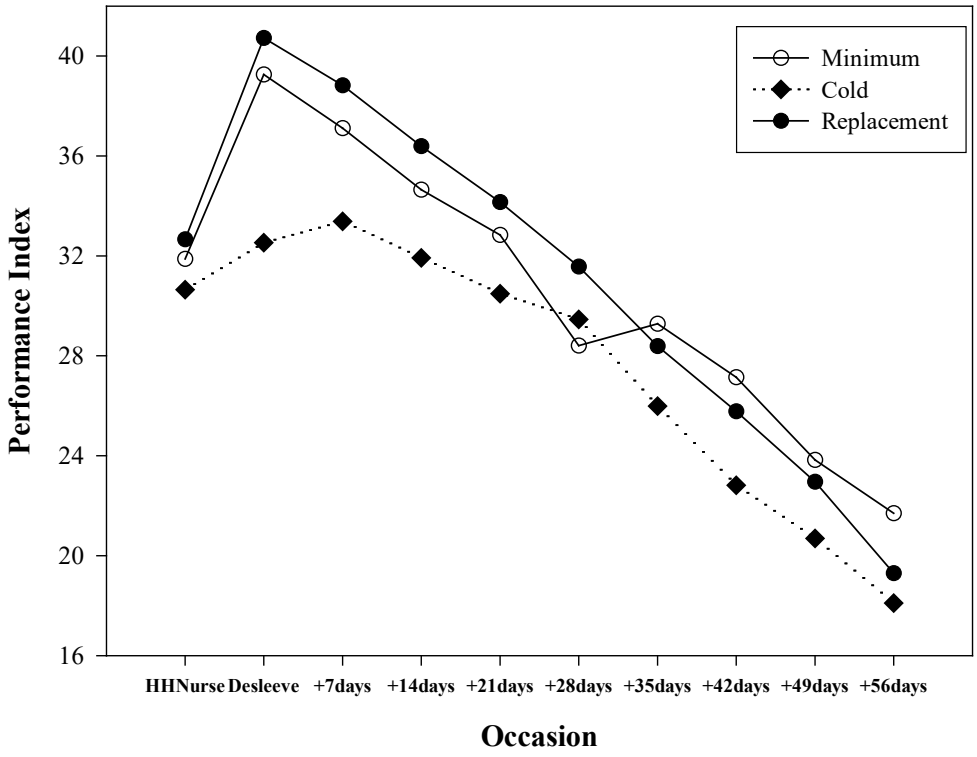

Fig. C. Effects of transport chain on chlorophyll fluorescence 'Performance Index' (PI) in poinsettia

Trends in PI for marketing chain from de-sleeving onwards were essentially similar to those indicated by expert quality assessment. This indicates that the measurement of PI at de-sleeving has good potential to show up batches of plants that have been stressed during transportation. However, to determine batch potential it will be necessary to obtain PI scores representative of all plants within the batch. It would be even more useful if PI scores were predictive for individual plants, but analysis showed that this was not the case. There appeared no obvious additional benefit of 'double-hit' tests.

Full tissue mineral analyses were done using bracts (red leaves) from plants at the production nursery, at the end of the simulated retail phase and at the end of home life. In Spotlight, the measured levels of phosphorus, potassium, calcium, magnesium and manganese changed little during marketing to de-sleeve and showed no effect of transport chain. However, levels of each of these elements increased by a proportionately large

amount from de-sleeving to the end of home-life. Nitrogen levels increased by a small, but significant amount, from the production nursery to the end of home-life.

In Sonora, levels of nitrogen, phosphorus and manganese changed little from the production nursery to the end of the trial. Potassium levels increased, but less markedly than in Spotlight. Calcium increased in Sonora in a similar way to that observed in Spotlight. Magnesium levels also increased in Sonora, but the increase was less marked than that seen in Spotlight.

The effects of home-life temperature on bract mineral content were significant and consistently observed across both cultivars. Plants in the higher home-life temperature treatment (21ºC) had higher levels of phosphorus, potassium, calcium, magnesium and manganese at the end of home-life than plants in the lower temperature room (16ºC). However, nitrogen levels did not differ significantly between the two temperature treatments at the end of home-life.

1.4.2. Begonia

Effects of transport chain on subsequent home-life quality appeared to be less marked in begonia than in poinsettia (Plate 5). Nevertheless, begonia pots subjected to minimum stress showed consistently higher flower counts throughout home life in both years than pots from the cold transport or commercial chains, and scored highest for overall plant quality during the middle weeks of home life in year 2. Cold transport resulted in flower counts at least as high as those for pots transported by the commercial chain except during the final two weeks of year 2. The commercial chains, Safeway in year 1 and Sainsbury in year 2, scored consistently lowest for overall expert plant quality score, especially during the final three weeks of home life in year 1. The reasons for this are not known.

Home-life temperature had by far the most obvious effect on quality decline after de-sleeving, and results in year 2 were broadly consistent with those in year 1. The higher temperature treatment (21ºC) accelerated quality decline compared with the lower temperature treatment (16ºC), giving rise to greater flower drop (see Fig. D) and greater coloured bud drop. It also resulted in lower total flower counts in year 2, presumably reflecting the increased flower drop. Substantial levels of green bud drop occurred only in year 1 and, again, was increased by the higher temperature. In both years, the 21ºC home-life treatment gave lower overall plant quality scores, flower quality scores, flower colour scores, foliar quality scores and foliar colour scores. In general, however, the detrimental effects of the higher temperature were shown earlier during home life in year 2 than in year 1.

High light (600 lux) gave consistently higher total flower counts throughout home life in year 2 than did low light (300 lux). This beneficial effect was also noted in year 1 but only from the third week onwards. In neither year did light have any marked effect on flower and bud drop, so high light must have its effect simply by promoting bud opening. High light also retarded the decline in flower colour score, relative to low light, in both years and this, together with increased flower numbers, was reflected in higher flower quality scores for the high light treatment. The difference in flower scores between the two light treatments increased progressively with time in both years. High light also gave increased foliage quality and foliage colour scores in year 2 but not in year 1.

The home-life combination of low temperature and high light was particularly beneficial to begonia longevity (Plate 6).

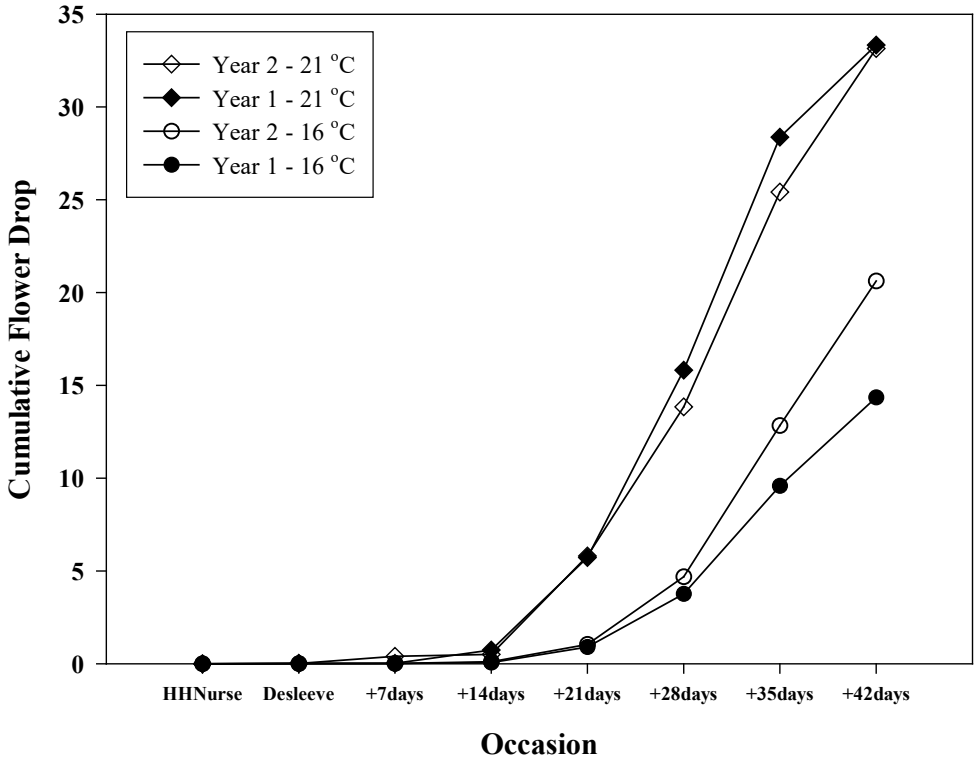

Fig. D. Effects of home-life temperature on cumulative flower drop in begonia

There was little obvious effect of fluctuating watering treatment on home-life quality in either year, but there was an effect of cultivar. Thus, coloured bud drop was much reduced in Batik compared to Balli in both years, and this was probably the reason why Batik gave consistently higher total flower counts than Balli. Batik out-scored Balli for overall plant quality and flower quality throughout home life in year 1 but, perhaps surprisingly, only during the final two weeks of home life in year 2. There were no obvious differences between the cultivars in either foliage quality or foliar colour.

As with poinsettia, objective quality loss functions were developed mathematically as a two-stage process. First, expert scores were related to the measured physiological variates to give objective quality scores, and these scores were than modelled over time. Fig. E shows the decline in quality modelled in this way for two contrasting treatments. It is noteworthy that for both poinsettia and begonia, highest quality during home life is given by the same combination of factors: minimum marketing stress, low home-life temperature, high light and standard watering.

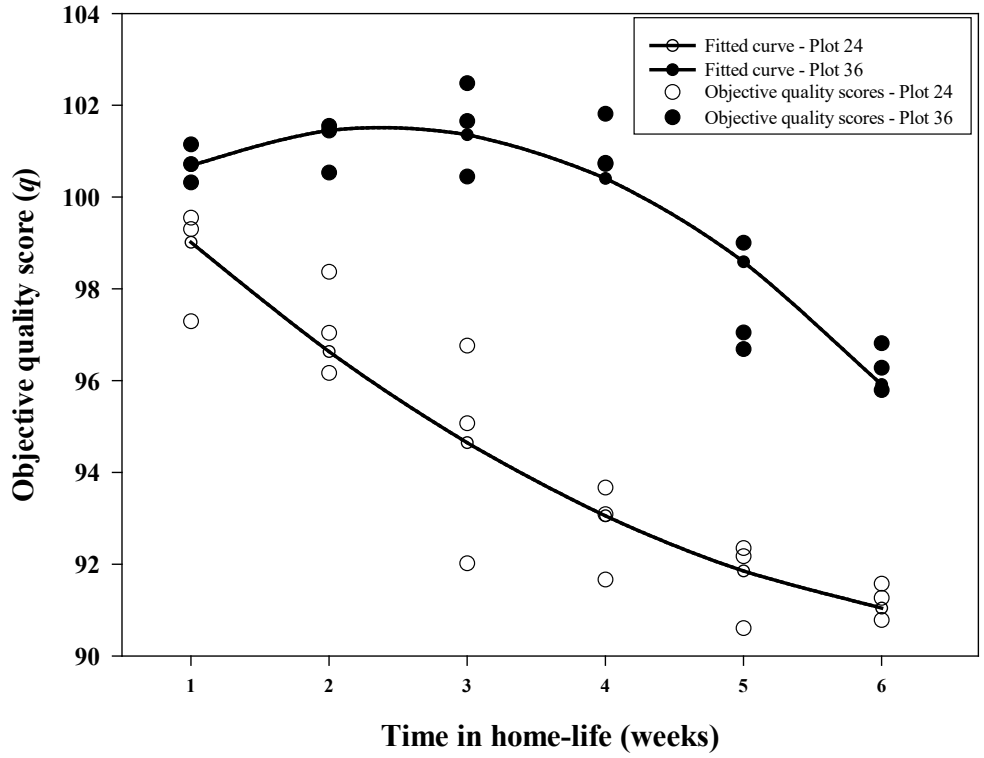

Fig. E. Modelled decline in quality during home life. Upper line: Batik, minimum marketing stress, 16 ºC home-life temperature, 600 lux and standard watering; lower line: Balli, Sainsbury chain, 21 ºC home-life temperature, 300 lux and fluctuating watering regime.

This modelling phase indicated the key physiological factors determining expert plant quality scores in begonia, and factors affecting the rate of quality decline. Thus:

Balli

- High flower counts improved plant quality.
- Flower drop reduced quality.
- Bud drop reduced quality.
- Damaged leaves reduced quality.
- High bud counts improved plant quality.
- A significant interaction between flower drop and bud drop indicated that the effects of flower drop on plant quality were less marked at higher bud drop than at lower bud drop.
- A significant interaction between flower drop and damaged leaf count indicated that the effects of flower drop on plant quality were less marked at higher damaged leaf counts than at lower counts.

- Quality was higher at a home-life temperature of 16ºC than at 21ºC.
- Quality was higher at 600 lux than at 300 lux.

- The rate of decline in plant quality was significantly slower in minimum transport stress plants than in plants from either the cold or Sainsbury chains.
- The rate of decline in plant quality was greater at low light (300 lux) than at high light (600 lux).
- Quality was significantly higher in the standard watering treatment for minimum transport stress plants than in all other combinations of watering and transport chain.

Batik

- High flower counts improved plant quality.
- Flower drop reduced quality.
- Bud drop reduced quality.
- Damaged leaves lowered quality.
- High bud counts improved quality.
- A significant interaction between flower drop and bud drop indicated that the effects of flower drop on plant quality were less marked at higher bud drop than at lower bud drop.

- Quality was higher at a home-life temperature of 16ºC than at 21ºC.
- Quality was significantly higher in minimum transport stress plants than in either cold or Sainsbury chain plants.
- Quality was higher at 600 lux than at 300 lux for plants from the cold and Sainsbury chains, but light had no effect on minimum transport stress plants.
- The rate of quality decline was greater at 21ºC than at 16ºC.
- The rate of quality decline was greater at low light (300 lux) than at high light (600 lux).

Chlorophyll fluorescence measurements showed a more or less continuous, linear decline from de-sleeve onwards. The PI index gave rather greater discrimination between treatments than Fv/Fm scores, and clearly showed up the detrimental effects of commercial transport chain in the early stages of home life (year 2 only) and of the higher home-life temperature (both years) (see Fig. F). The PI index also gave consistently higher scores for cultivar Batik as compared to Balli in both years, consistent with Batik having received higher plant quality ratings. Of particular note, however, were the much higher PI scores for middle-canopy leaves as opposed to upper or lower canopy leaves. The importance of leaf position is clearly a factor that would need to be taken into account in developing chlorophyll fluorescence as an objective means of assessing plant quality.

As with poinsettia, it is clear that the measurement of PI index has good potential to show up batches of begonia plants that have been stressed during transportation. However, to determine batch potential it will be necessary to obtain PI scores representative of all plants within the batch. The PI scores did not prove predictive for individual plants. There appeared no obvious additional benefit of 'double-hit' chlorophyll fluorescence tests.

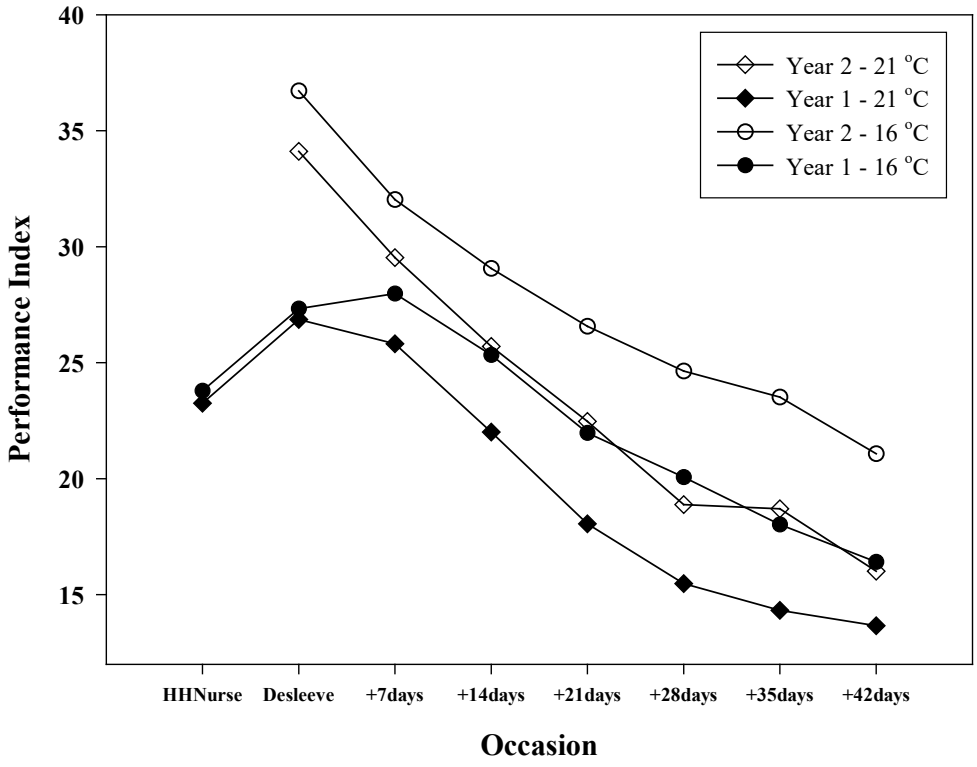

Fig. F. Effects of home-life temperature on chlorophyll fluorescence 'Performance Index' (PI) in begonia

Full plant tissue mineral analyses were done at the production nursery, at the end of the simulated retail phase and at the end of home life. Nitrogen and potassium levels did not differ significantly between the nursery, de-sleeve and the end of home life. There were increases between the nursery and de-sleeving in the content of phosphorus, calcium and magnesium (Balli only), and decreases from de-sleeving to the end of home-life in the content of manganese (Balli only). Effects of chain and home-life treatments on leaf mineral content were, overall, small. The only significant effect was a small rise in leaf manganese content in the fluctuating watering treatment at the end of home life.