Project title: Horticultural crops: Further demonstration of the potential benefits of modified plastic crop covers

Project number: CP 19

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Authentication

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

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Grower Summary

Headlines

- The overall aim of this project is to evaluate and demonstrate effects of five spectral filters on a wide range of commercially important crops that have been chosen by a consortium of growers (the Grower Steering Group).
- With the assistance of Haygrove Tunnels and bpi.Agri, a development and demonstration facility was established at STC consisting of five tunnels and an open field plot, each of 740m^2.
- The first year's work showed some marked effects of filters on plant growth regulation, canopy development, time to flowering and colour intensity. These effects varied between plant species / cultivars.
- More detailed scientific studies, using young propagation lettuce plants as a model, provided an insight into some of the underlying physiological changes, particularly related to cell expansion.
- A filter which modified the ratio of red : far red light reaching the crop showed potential to regulate plant growth, which could provide an alternative to chemical growth regulators in some crops.
- In Lollo rosso, foliar pigmentation was much more intense when grown under the UV-transparent filter.
- Initial observations on young cabbage plants grown under a red / far red modifying film indicated that changes in leaf colour may be linked to increased plant surface waxes. More detailed investigations will determine whether this affects influences hardening off and / or resistance to pest attack.
- Young lettuce plants partly raised under red / far red modifying and UV transparent films were consistently shorter and stockier than those produced by the commercial standard. When planted out in the field, both produced yields approximately 24% above the same standard.
- The UV-transparent filter produced flowers with more intense colouration in red and blue Asters, and red and blue Pansies.
- Plant canopy development was altered in a number of crops grown under various filters. An increase in vegetative cover was observed in Asters under a red / far red modifying film. A number of growth modifications were recorded in the various perennial herbs but these effects were complex and varied between plant species.
- Although essential oil composition was not effected by the spectral filters, total essential oil yield was increased by between 5% (Thyme) and 541% (Sage) under UV-opaque when compared to the open plot. Indeed total oil yield was generally increased under all filters relative to open plot plants.

Project background and expected deliverables

The cultivation of crops under simple plastic covered structures is now commonplace in UK horticulture because of its potential to extend growing seasons, control harvests and improve the quality of produce. In recent years advances in technology have allowed the manufacture of novel materials that 'fine-tune' the growing environment still further, by manipulating the quantity and wavelength of light reaching the crop.

Much of the international research on modified plastics has been carried out in warm climates and has concentrated on the absorption of UV light to reduce the scorching effects of the sun, to manipulate pest behaviour, and to reduce establishment of certain pathogens. However, in the UK there may be greater benefits from improving transmission of UV light, which could harden the plant cuticle, reduce the trauma of planting out, improve resistance to pests and disease, reduce the need for artificial growth regulators, increase oil content of aromatic plants and improve colour intensity of flowers and foliage. More specifically, the manipulation of the red : far red ratio can provide predictable modification of plant growth, while the manipulation of infra red wavelengths can have a cooling effect in summer, which could improve the quality of certain cut flowers.

Although a limited number of small-scale studies have investigated the potential impacts of this technology on UK crop production, the majority of large-scale work has been carried out on crops common to arid regions. In contrast, the aim of this long-term, large-scale project is to investigate the costs and benefits to the UK horticultural industry of adopting modern plastic technology, by concentrating on crops that are of specific importance to the UK market. This project will clarify the situation by evaluating plastic covers with a broad range of light manipulating properties, determine their benefits to key UK horticultural crops and rapidly transfer that technology to UK growers. In addition, the proposed research will provide direction for more fundamental scientific studies to determine the underlying mechanisms, with a view to further enhancing the beneficial effects of such filters, and aiding in the development of new spectral filters.

Summary of work completed to date.

The following tasks have been completed in accordance with the first year's original objectives:

1. Literature search and initial consultation with overseas workers.
2. Initial liaison with manufacturers.
3. Assembled and covered tunnels.
4. Selected key indicator plants from each category.
5 Completed measurement and interpretation of light in structures.
6. Completed agronomic assessment of first year crops.

In addition, the following work has been completed under modifications to the work plan agreed on 16 July 2003.

1. Assessment of an additional sequence of three plantings of pansy.
2. Lettuce was used as a model to begin to investigate physiological changes.
3. Further work on lettuce plants in propagation included:
    a. Transfer of lettuce plants from the normal production system to the standard, UV transparent and Solatrol clad tunnels at different growth stages.
    b. Transfer plants from each batch to field plots to compare the rate of establishment, effect on harvest date and yield / quality at harvest.

4. Brassica plants were transferred to field plots to compare the rate of establishment, effect on harvest date and yield / quality at harvest.
5. Asparagus plants were obtained and potted ready for planting in 2004.

The facility

With the assistance of Haygrove Tunnels and bpi.Agri, a facility was established at STC Ltd to do this work under the combined management of applied scientists, agronomists, product suppliers and potential end-users. Five modified plastics were selected that represented the range of properties exhibited by materials currently available, i.e.:

- Standard clear horticultural film
- Diffusing standard film (Luminance)
- Red / far red modified film (designed to increase R:FR ratio) (Solatrol)
- UV-B transparent film (designed to transmit the full solar UV spectrum)
- UV opaque film

Each plastic was used to cover a 740m^2 structure and they were compared to an open field plot.

The following range of plants were selected for inclusion by the Grower Steering Group (GSG) (see Appendix 1 of full report):

- Vegetable propagation (cauliflower, cabbage, lettuce).
- Leafy salads (rocket, corn salad, chard, pak choi, lolla rossa, endive)
- Cut flowers (Asters, Stocks, Larkspur, Delphiniums)
- Bedding plants (Petunias, Impatiens, Dianthus, Geranium, Antirrhinum, Primula, Pansy)
- HONS (Chamaecyparis, Cotinus, Elaeagnus, Photinia, Choisya, Lavendula, Viburnum, Hebe, Calluna)
- Soft fruit (June bearers, Ever bearers)
- Herbs (Rosemary, Sage, Lavender, Thyme, Black Peppermint)

Summary of agronomic studies

The overall aim in the first year was to detect clear differences in growth and quality of the selected indicator plants and to provide direction for further R&D. The initial results showed marked effects on plant growth regulation, canopy development, time to flowering, colour intensity and yield of essential oils. However, these effects varied between plant species and cultivars. All the data are provided in the "Science Section" of this report. The following summary highlights the results that could have the most commercial relevance:

Plant growth regulation:

Growth regulation effects were observed with several of the plant species, most notably propagation vegetables and bedding plants. The clearest results showed with lettuce, which were quantifiable within 7-14 days under UV-transparent and Solatrol films. In both cases, the plants met a primary requirement of the GSG by being "shorter and stockier" than the standard controls. This effect is desirable with propagation vegetables because the plants are less likely to suffer damage during mechanised planting. It also has the potential to reduce the requirement for applications of chemical plant growth regulators (PGR) to certain bedding plants.

Young cabbage plants grown under Solatrol had the most well-developed root system.

More detailed scientific studies, using lettuce as the model crop, showed that the growth regulation could be attributed to reductions in cell expansion, rather than reductions in cell numbers. With plants raised under the UV-transparent film, there was an associated increase in leaf thickness due to the presence of more rows of photosynthesising cells. The latter is a well-recognised adaptation of many plant species to changing environmental conditions (e.g. increases in UV and photosynthetically active radiation) and could aid the plants to adapt more quickly to ambient conditions when planted out in the field.

Following planting out in the field, the lettuces grown under Solatrol and UV transparent films produced yields approximately 24% above the standard material. However, in these trials, the early developmental changes had no discernable effect on final fresh weights of cabbage at harvest.

Canopy development / fresh weight yield:

The growth regulation effects reported above relate to plants that were grown under the various plastics prior to be planting out in the field. However, effects were also seen in plants that were grown in the tunnels to the point of harvest. These included the perennial herbs, leafy salads and cut flowers.

The results suggest that there are significant gains to be made in terms of both fresh and dry weights of perennial herbs by switching production to the UV-opaque filter from either outdoor or the standard cladding material. The UV-opaque filter clearly increased fresh weights in Lavender, Peppermint, Sage and Thyme, and increased dry weights in Lavender, Sage and Thyme.

Productivity of Endive varied greatly under the filters. Both Standard and UV-transparent produced increases in total leaf areas, plant fresh weights and leaf thickness, especially when compared to Solatrol and conventionally produced field plants. Further investigations in the second year's trials will seek to clarify whether these productivity increases are accompanied by beneficial changes in crop quality, particularly the level of natural blanching of the leaf stems. With Swiss chard, it was clear that plant fresh weights were significantly increased under all five filters compared to conventionally produced field plants. While these results pointed to increased crop productivity in both Standard and UV-opaque, there was a high degree of variability and further studies are required to clarify the potential economic benefits.

The results from the cut flowers varied between species. Although defining canopy development is difficult, it may be considered to encompass interactions between break numbers, internode length and total leaf area. In Asters, there was a very clear effect of certain filters on canopy development; e.g. Solatrol produced more a dense canopy, which could translate into more marketable product. In Stocks, there was a general trend for increased length and number of flowers in the terminal inflorescence under the Solatrol filter. Larkspur grown in the field produced plants with more pronounced vegetative growth (i.e. in the form of increased numbers of ancillary breaks) compared to those grown under the plastic covers. Results from Delphinium were somewhat more complex. Tentative evidence suggested that both terminal inflorescence and ancillary flower numbers were increased under Luminance. There was also evidence to suggest that the length of the terminal inflorescence was generally increased under both Solatrol and UV-opaque.

Flower development and time to flowering:

There were clear examples of flower development being modified by the filters. In Antirrhinums, the total number of flowers per plant was increased under the standard filter, and reduced under Solatrol compared with Field. The diameter of the flower was increased in blue Pansy under the Luminance filter and in yellow Pansy under the UV-opaque filter.

In both Antirrhinums and blue Pansy, the time to harvest was increased by several days in those plants grown under the Solatrol filter, while for red and yellow Pansy, time to harvest was reduced under the UV-opaque filter.

Pigmentation and colour intensity:

Both Standard and UV-transparent filters produced (visually) increased levels of red pigmentation in Lolla rossa when compared to the other treatments, which is highly desirable for this crop when retailed in mixed leafy salad packs. The colouration under Solatrol was also modified but in this case it was almost brown, which was not so attractive. The Standard filter was probably best overall for Lolla rossa because it produced plants with higher fresh and dry weights than the UV-transparent filter.

The leaves of propagation brassicas grown under Solatrol were dark blue-green compared to those grown under the other filters. Preliminary visual assessments suggested that this colouration was associated with increased leaf surface wax development, which could have implications for tolerance to pest and disease.

More intense flower colouration was observed in blue and red Pansy grown under the UV-transparent filter. This suggests that certain cultivars of Pansy may respond to high levels of UV light by increasing concentrations of a range of pigments, which as well as acting as "sunscreens" against potentially damaging effects of UV, also contribute to flower colouration".

The colour of flowers of the red and blue asters grown in both in the field and under the UV-transparent filter was visibly more intense than those grown under the other plastics. This was part of a complex of changes to the size and appearance of Aster flowers that will be investigated in more detail.

Oil content:

Preliminary results from essential oil analysis suggest that there was no apparent effect of filters on the composition of essential oils. However, total oil yield was generally increased under all filters relative to the open plot; for example total oil yield was increased by between 5% (Thyme) and 541% (Sage) under UV-opaque when compared to the open plot.

Financial benefits to growers

Potential benefits:

The list of potential benefits identified at the start of this project remains unchanged. These will vary between different combinations of plant species and modified plastics, but they are likely to include:

- Reduction of use of chemical growth regulators.
- Reduction of pesticide use, with consequent reductions in residues persisting in the final crop, and in the risk of broader environmental effects associated with agrochemical use.
- Improved quality of crops.
- Reduce wastage due to failure to meet QC standards.
- Improved crop scheduling and extension of the growing season.
- Reduction of hardening off periods and plant losses during that critical phase.
- Opportunity to grow crops that are normally imported.

On the basis of the data obtained during 2003-4, a number of additional benefits have been identified:

- Improved pigmentation of foliage (e.g. in coloured-leaved lettuce) and flowers (e.g. Pansy and Asters).
- Increased quantities of essential oils in herb crops due to increases in plant biomass.

One of the tasks of the project is to liaise with the grower steering group to calculate the potential financial benefits of the factors listed above and to determine the economic viability of adopting the new growing systems.

Action points for growers:

The Project Management Team and GSG do not believe that it is appropriate to make firm recommendations on the basis of 2003 results alone. However, the key findings for the first year's studies have been identified and will form the basis of a restructured work plan.

Technology transfer:

Rapid dissemination of information from the project to HDC members forms an integral part of this project. This will be facilitated by the structure of the project consortium, which comprises applied scientists, agronomists, product suppliers and potential end-users.

SCIENCE SECTION

SECTION A. GENERAL INTRODUCTION

Project background

The cultivation of crops under simple plastic covered structures is now commonplace in UK horticulture because of its potential to extend growing seasons, control harvests and improve the quality of produce. In recent years advances in technology have allowed the manufacture of novel materials that 'fine-tune' the growing environment still further, by manipulating the intensity and wavelength of light reaching the crop.

Much of the international research on spectrally modified plastics has been carried out in warm climates and has concentrated on reducing the transmission of UV light (280-400nm in sunlight) compared with standard films, to reduce the scorching effects of the sun, to manipulate pest behaviour, and to reduce sporulation of certain pathogens. However, in the UK there may be benefits from improving transmission of UV light compared with standard plastics. Increasing UV can harden the plant cuticle, reduce the trauma of planting out, improve resistance to pests and disease, reduce the need for artificial growth regulators, increase oil content of aromatic plants and improve colour intensity of flowers and foliage. Spectral modification at wavelengths longer than UV are also exploited. The manipulation of blue wavelengths (broadly 400-500nm) has been reported to control a number of economically relevant diseases. The manipulation of the red : far red ratio (centred on 650 and 730nm respectively) can provide predictable modification of plant growth. Finally, increasing the light scattering ("diffusing") properties of films, can reduce solar heat load due to infra red wavelengths and so a cooling effect in summer, which could improve the quality of certain cut flowers, improve fruit yield in strawberry etc.

Although a limited number of small-scale studies have investigated the potential impacts of spectrally modified plastics on UK crop production, the majority of published research studies come from regions with hotter, sunnier climates which may be hard to extrapolate to UK conditions. Therefore, to date, UK growers have been presented with little objective information about the effects of modified plastic covers under UK conditions and using structures approaching the commercial scales.

The aim of this long-term, large-scale project is to investigate the technical and economic benefits to the UK horticultural industry of adopting modern plastic technology, by concentrating on crops that are of specific importance to the UK market. This project will clarify the situation by evaluating plastic covers with a broad range of light manipulating properties, determine their benefits to key UK horticultural crops and rapidly transfer that technology to UK growers. In addition, the proposed research will provide direction for more fundamental scientific studies to determine the underlying mechanisms, with a view to further enhancing the beneficial effects of such filters, and aiding in the development of new spectral filters.

Commercial objectives

The project has been driven by a consortium of growers from a wide range of commodity sectors (led by horticultural consultant, Mr Stuart Coutts) who form the project's Grower Steering Group. The project also has the support of the leading tunnel and plastic manufacturers. The partnership of applied scientists, agronomists, product suppliers and potential end-users will ensure that the materials are properly evaluated under conditions relevant to commercial crop production and that the results become available to growers as quickly as possible.

Summary of work completed in the first year of the project in accordance with initial HDC funding proposal (January, 2002).

3. Completed literature search and initial consultation with overseas workers.
4. Completed initial liaison with manufacturers.
5. Assembled and covered tunnels.
6. Selected key indicator plants from each category.
5 Completed measurement and interpretation of light in structures.
6. Completed agronomic assessment of first year crops.

Summary of additional work completed under modifications to work plan agreed 16th July 2003.

6. Assessment of an additional sequence of three plantings of pansy.
7. Lettuce was used as a model to begin to investigate physiological changes.
8. Further work on lettuce plants in propagation included:
    a. Transfer of lettuce plants from the normal production system to the standard, UV transparent and Solatrol clad tunnels at different stages.
    b. Transfer plants from each batch to field plots to compare the rate of establishment, effect on harvest date and yield / quality at harvest.
9. Brassica plants were transferred to field plots to compare the rate of establishment, effect on harvest date and yield / quality at harvest.
10. Asparagus plants were obtained and potted ready for planting in 2004.

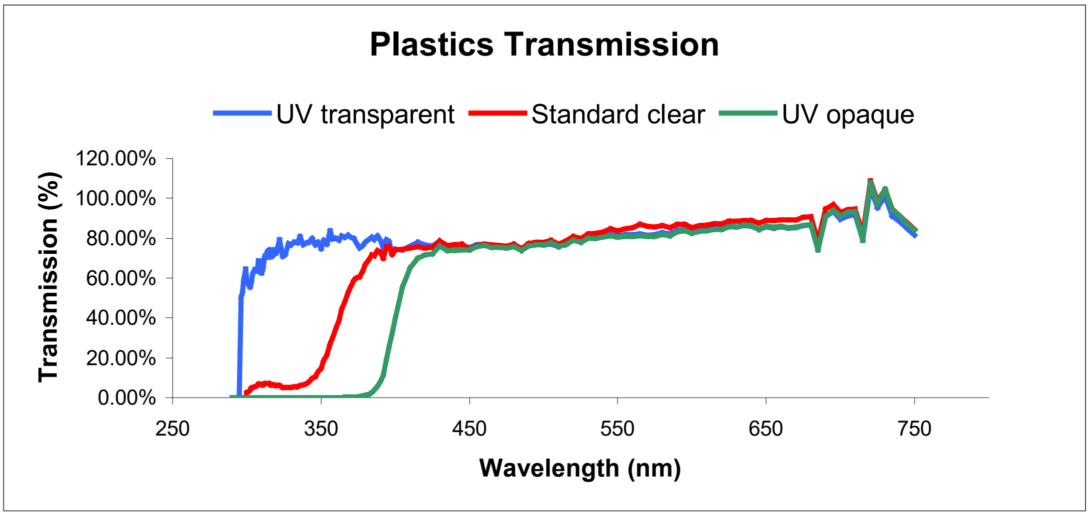
Figure 1. Large scale spectral filter trial (Stockbridge Technology Centre, Summer 2003).

SECTION B. MATERIALS AND METHODS

Spectral filters.
Plants were grown, following grower instructions, under five spectral filters (Standard, UV-transparent, Solatrol, Luminance and UV-opaque) provided by BPI Agri (Stockton-on-Tees, UK). Each plastic altered the spectrum of light under the canopy in the way detailed below (Figs. 1.a. - 1.e). A Mypex covered open field plot was also used.

Measurement of irradiance
Spectral irradiances within the polytunnels were measured relative to ambient spectral irradiances using two double monochromator spectoradiometers (S9910-PC and SR9910-V7, Macam Photometrics, Livingston, UK). The spectroradiometers were calibrated for wavelength using spectral lines from a mercury arc lamp (LOT Oriel, Leatherhead, UK) and for spectral irradiance against tungsten and deuterium sources (Macam SR903) based on National Physics Laboratory Standards.

a)



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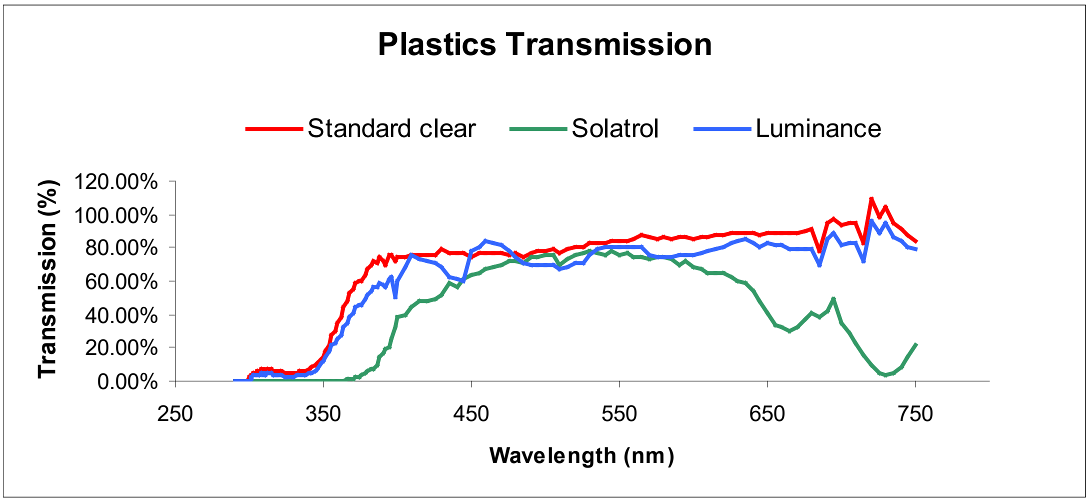

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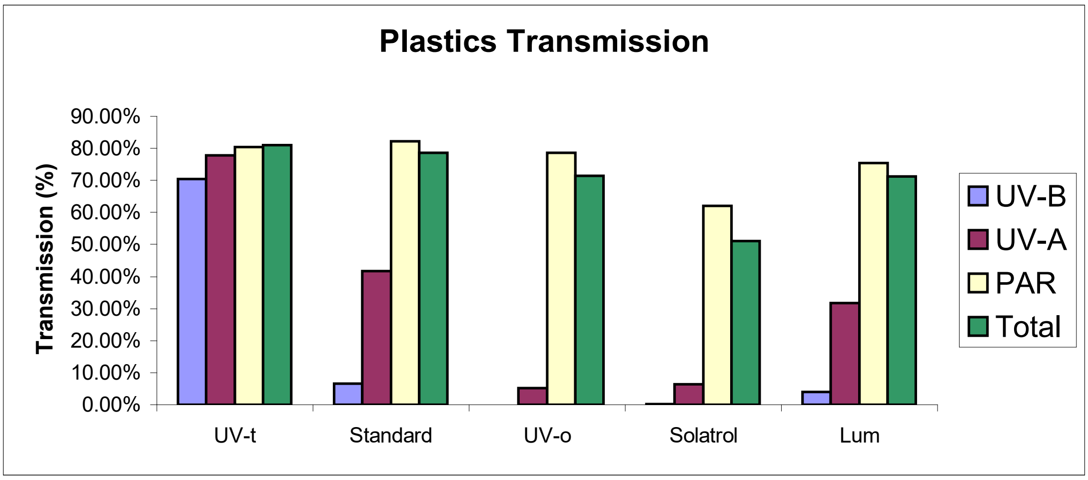

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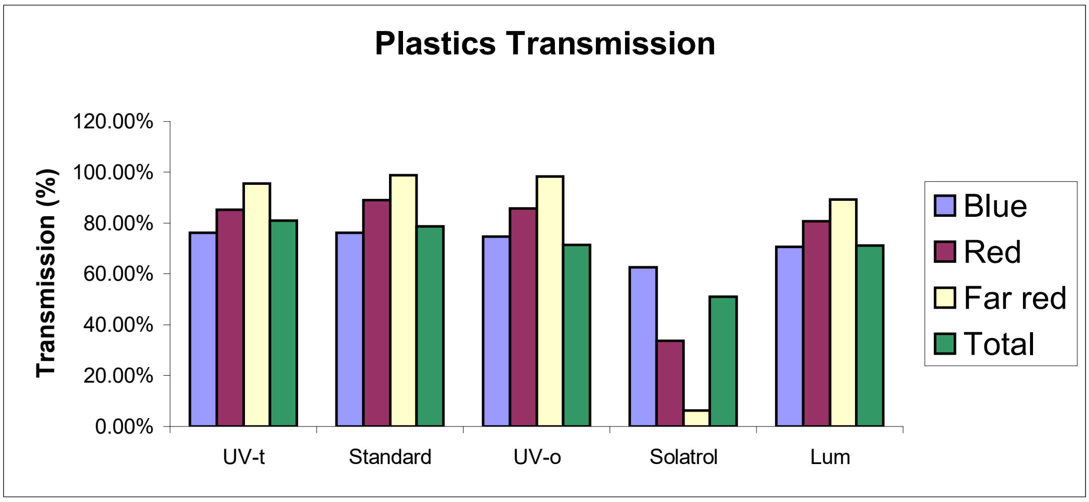

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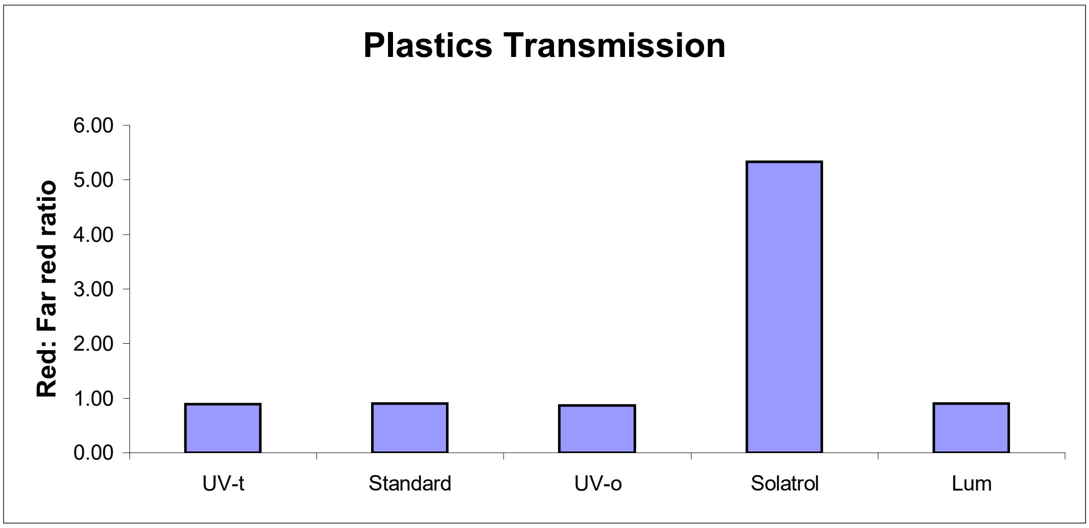
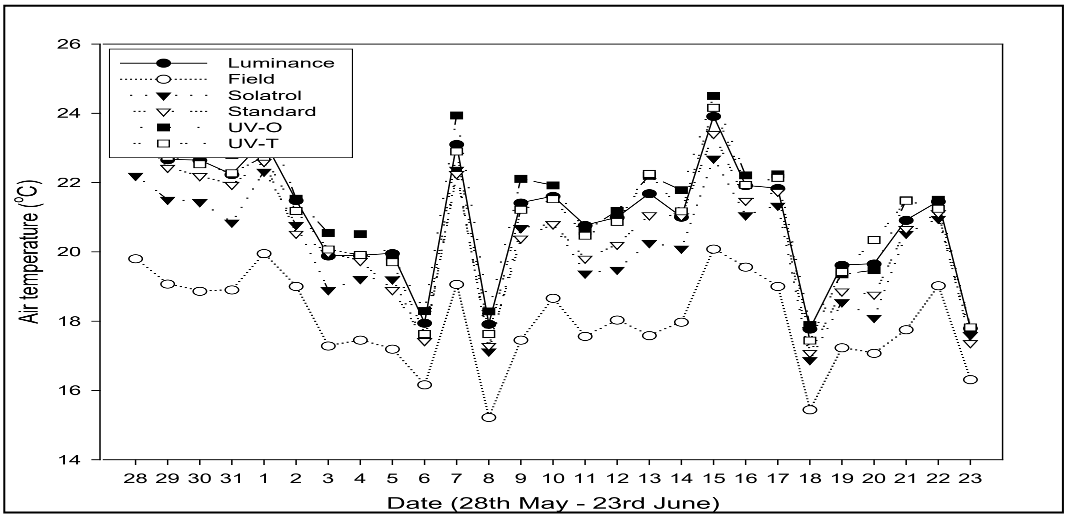


Figure 1. Light measurements taken at Stockbridge Technology Centre in August 2004.

Measurements of temperature and humidity
Temperature and humidity measurements were taken once per hour from the 28 May to the 23 June 2003 (Fig. 2).

a)



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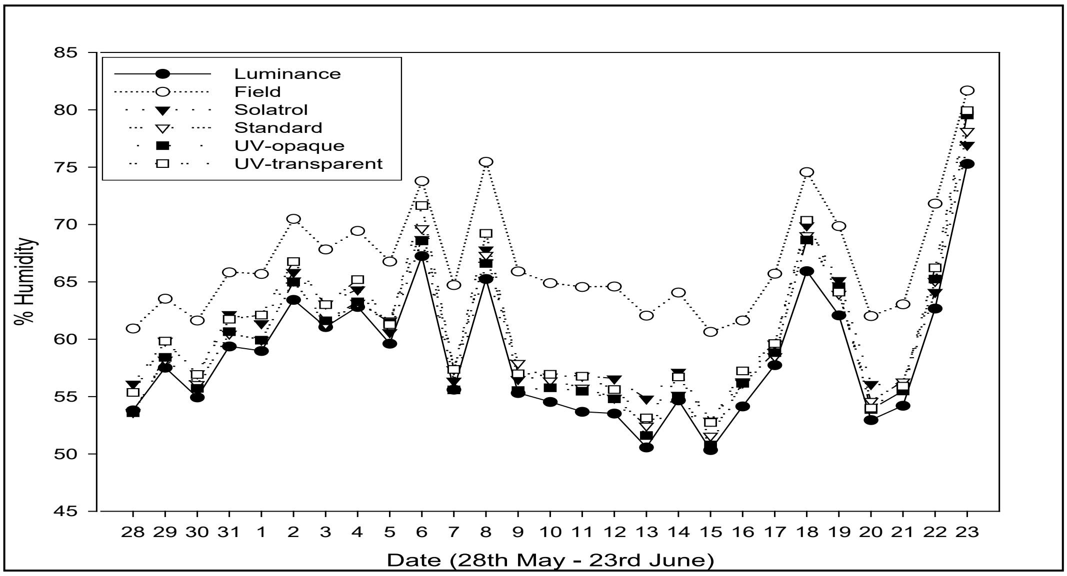


Figure 2. Representation of both air temperature and humidity under all five filters and in the field plot.

Determination of root / shoot fresh and dry weights.
Plants were harvested at the time of first flower (unless otherwise stated) and shoot / root fresh weights were determined. Shoot / root dry weights were obtained by weighing the plant material after drying at 75 °C until a constant mass was reached.

Leaf expansion measurements.

Daily expansion was measured from the time of leaf emergence. Both length and width measurements were taken at the widest point using electronic digital callipers and area calculated accordingly (Screwfix Direct, Yeovil, UK).

Daily area growth increments, which correlate highly with absolute leaf area (r^2 = 0.97 - 0.99, depending on species), were calculated from lengths and widths, measured using a LI-3100 area meter (LI-COR Inc, Lincoln, Nebraska, USA) at destructive harvests throughout development.

In instances where destructive harvests were made determination of leaf area was estimated using an automatic Leaf Area Meter LI-3000 (Li-Cor, Inc., Lincoln, NE, USA).

Photosynthesis measurements.

Measurements of light saturated photosynthesis (1500 μmol m^{-2} s^{-1}) using a Portable infra-red gas analysis system (CIRAS- 1, PP systems, Hitchin, UK) were made on leaf two of lettuce, always between 9:00 a.m. and 13:00 p.m., starting six days after leaf emergence and continuing for 14 d.

Epidermal cell size and cell numbers.

At 20 d after emergence, leaf two of lettuce was removed following the cessation of growth, in order to measure epidermal cell size using the dental rubber impression technique (Weyers & Johansen 1985; Poole *et al*. 1996). Measurements were made at the central region of the lamina. The procedure involved first covering the leaf surface with dental impression material (Xantopren, Dental Linkline, UK) to make an imprint of the epidermal surface area. Once the material had set (30-60 s) the leaf was peeled away. Acrylic-based nail varnish was used to produce a translucent positive replica from the negative rubber impression. Cell size was measured at 400X magnification using a Leitz 'Labovert' (Leica, UK) microscope fitted with a ½ inch CCD digital video camera (JVC, Japan). Final leaf area of leaf two was also determined before harvest using the method described in a previous section.

Leaf thickness.

Leaf thickness was measured at the central region of the lamina, adjacent to the mid-vein, using a 0-25mm micrometer (RS Components, Corby, UK).

Light microscopy.

Samples were dissected into small pieces approximately 5mm square ready for processing. Samples were fixed in 4% glutaraldehyde in PBS (Sigma, UK) for 2 hours and washed three times in PBS for 15 minutes at each wash before being passed through a graded alcohol series (50%, 70%, 80%, 90%, 95% and 100%). Samples were transferred to LR White resin (TAAB Laboratories, UK) and agitated for one hour. This process was repeated with subsequent washes under agitation in fresh resin for one hour and overnight. The samples were then embedded in moulds containing fresh resin and polymerised at 50°C for 24 hours. Semi-thin sections were cut on a Reichert Ultracut E microtome (UK) and collected on cleaned glass slides prior to examination at 400X magnification on a Leitz 'Labovert' (Leica, UK) microscope fitted with a high resolution digital camera (JVC, Japan).

Field trials.

Preliminary field trials of Lettuce and Brassica were carried out beginning on the 29 August 2003. Plants were removed from their respective spectral filters and planted out in a random block design (Fig. 3).

Figure 3. Field plot used for Brassica and lettuce trials. Stockbridge Technology Centre, August 2003.

Hardy ornamental nursery stock market assessments

Plants were assessed in accordance with agreed marketing index. Briefly, the marketing score grades between 0 and 5; where 0 is dead, 1 is unmarketable, 2 is of borderline marketability (depending on the customers specification), 3 is acceptable to major retail outlets, and 4 and 5 represent quality above that standard.

Statistical analysis.

Multiple Student t-tests were used in all analysis except when calculating daily leaf expansion in lettuce. Because the same leaves were measured throughout the lettuce growth experiment (See part 3, fig. 3.2.a), leaf area data were analysed using two way, repeated measures ANOVA with *post hoc* multiple pairwise comparison using Tukey tests to investigate the effect of treatments on leaf area during development. All analyses were performed using Sigmastat V 2.03 (SPSS Inc.).

SECTION C. RESULTS SECTION

Part 1. Propagated lettuce (The “model” plant).

Introduction

A UK based plant propagator has been conducting trials with lettuce grown experimentally under a Luminance-type plastic for a number of years, but with less than satisfactory results. Plants have exhibited abnormally elongated leaves, either due to increased cell division or cell expansion, or both. Lamina tissue also possessed reduced mechanical strength when compared to glasshouse grown plants, which is likely due to changes in the architecture, and hence the mechanical properties, of the cell wall.

The dynamic character of the cell wall provides a mechanism(s) with which plants are able to selectively modify the extracellular matrix of different cell types, as a consequence of growth and differentiation, and in response to biotic stress (e.g. pests and disease) and changes in the abiotic environment (e.g. drought and elevated UV) (Cosgrove, 2001; Akiyama & Pillai, 2001; Peters, Hagemann & Tomos, 2000). The cell wall fulfils a variety of functions including maintaining / determining cell shape (Cosgrove, 1993). It provides mechanical strength and support preventing the cell membrane from bursting in a hypotonic medium (i.e. resists water pressure) (Cosgrove, 1993). Plant cell growth is defined as an irreversible increase in cell volume and can occur either by expansion (increase in cell size in two or three dimensions), or by elongation (expansion which is constrained preferentially to one dimension). In order for growth to occur these walls must expand through the shearing of the wall structure and the creation of new surface area material, while remaining strong enough to withstand the large mechanical stresses associated with turgor pressure (Fry, 1986).

Any investigation into beneficial changes in whole plant morphology under altered light regimes must include detailed studies of changes in cell division and expansion if the underlying mechanisms are to be understood and spectral filter technology is to develop. Therefore, the purpose of this study was to trial all five spectral filters with a view to identifying which plastics, if any, are capable of altering lettuce development in such a way as to increase the mechanical strength of the tissue, through changes in the properties of the plant cell wall and reduce abnormal lamina elongation, leading to the production of a more economically viable crop.

Objectives

To identify a filter(s) that produces a plant that is “short and stocky”, possesses good mechanical strength and that performs well in the field. This will allow lettuce plant propagators to bypass the ‘hardening-off’ stage of production and reduce production costs.

Results

FINAL LEAF AREAS

There was no effect of treatments on time to emergence of leaves one and two (data not presented).

There was no effect of UV-transparent filters on the final area of the first leaf when compared to the Standard (Fig. 1). However, when compared to Solatrol, plants grown under Luminance ($P<0.001$) and UV-opaque ($P<0.001$) filters did exhibit an increase in final leaf area (Fig. 1). The observed effect on total leaf area was largely a function of changes along the length axis, since there was relatively little effect of the filters on the width of the leaves (data not presented).

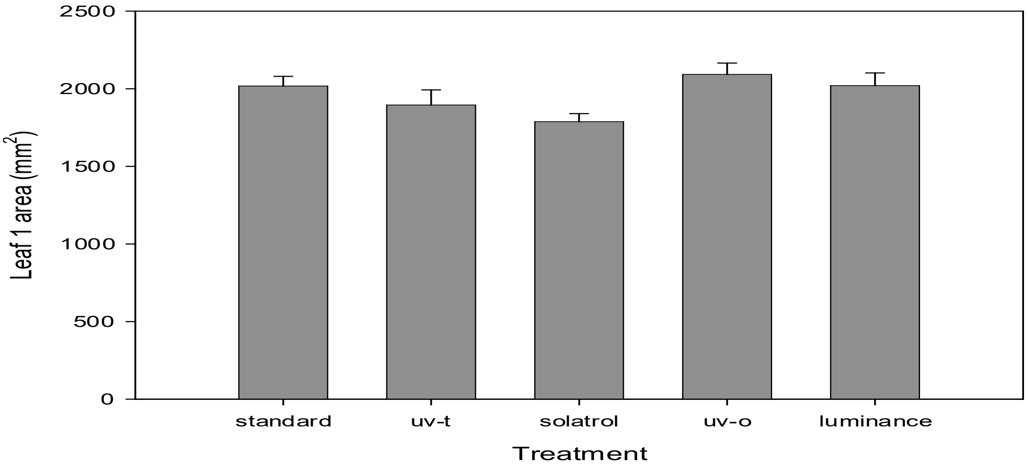


Figure 1. Effect of treatments on area of leaf 1 of propagation lettuce. Measurements taken at 14 days after treatments began. Each value is the mean ± S.E. of 12 replicates.

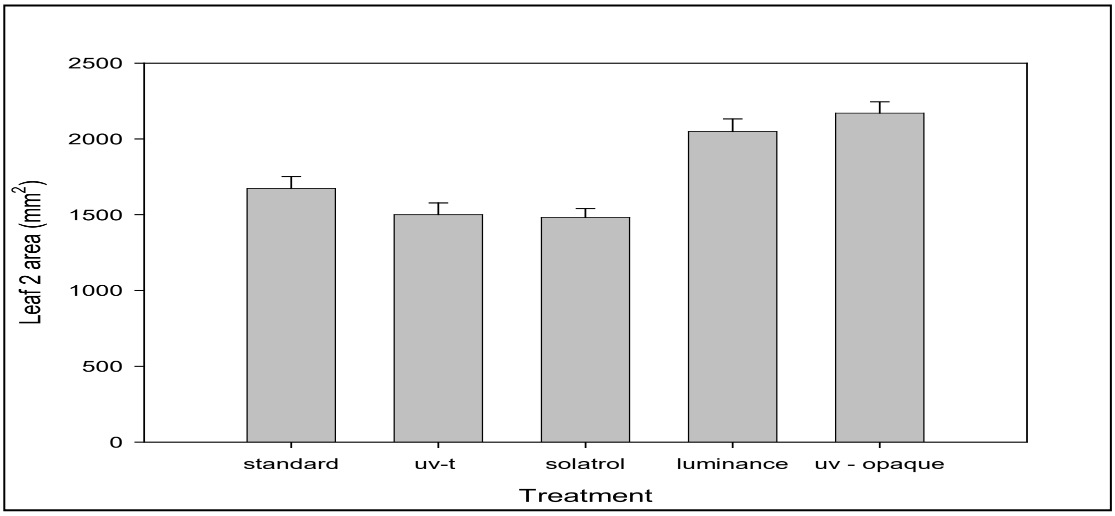


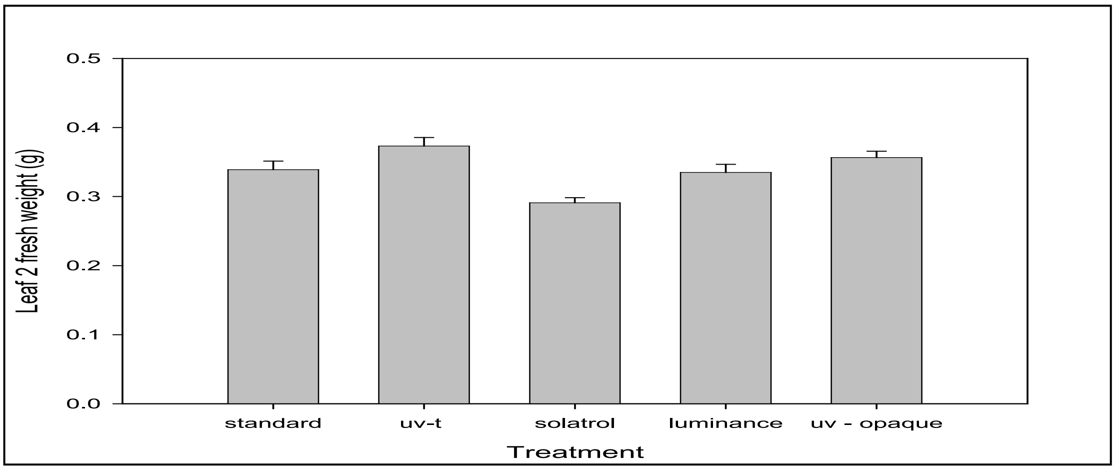
Figure 2. Effect of treatments on area of leaf 2 of propagation lettuce. Measurements taken at 14 days after treatment began. Each value is the mean ± S.E. of 12 replicates.

In leaf two, the UV-transparent filter reduced final leaf areas when compared to both Luminance and UV-opaque plastics, although there was no significant effect relative to the Standard (Fig. 2). Similarly, there was no effect of Solatrol when compared to Standard, however, final leaf areas were significantly reduced relative to both Luminance and UV-opaque filters. As in leaf 1, the effects of filters on final leaf area was again closely linked to changes along the length axis (data not presented).

LEAF TWO FRESH / DRY WEIGHT

UV-transparent exhibited increased fresh weights when compared to both Solatrol (P<0.001, Fig. 3.a) and Luminance (P<0.05, Fig. 3.a), although there was no significant effect relative to UV-opaque (P>0.05, Fig. 3.a) and Standard (P>0.05, Fig. 3.a) filters. Leaf two fresh weights of lettuce grown under Solatrol were significantly reduced when compared to all treatments (P<0.001, Fig. 3.a).

a)



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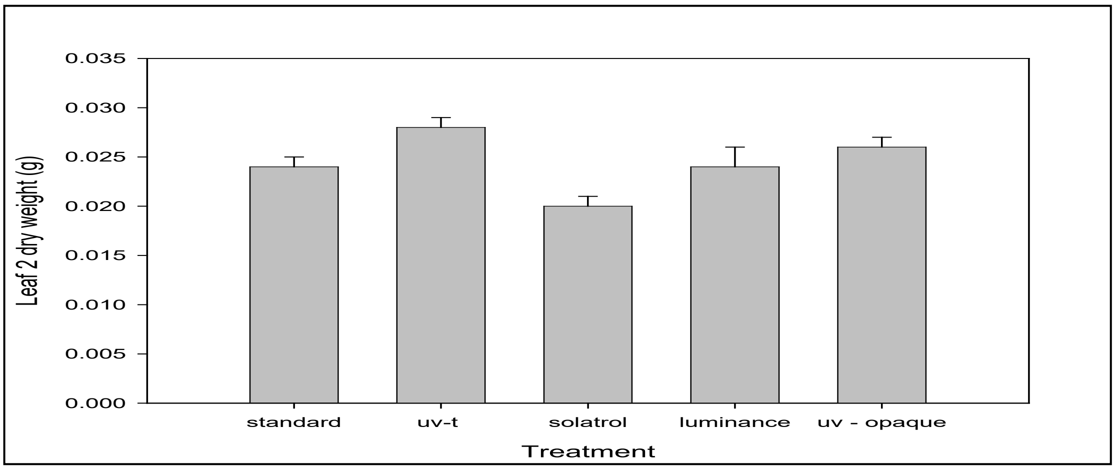


Figure 3. Effect of treatments on (a) fresh and (b) dry weight of leaf 2 of propagation lettuce. Harvest and determination of weights was made at 14 days after treatment began. Each value is the mean ± S.E. of 15 replicates.

A similar pattern was observed in the dry weight data. Again, Solatrol reduced dry weights when compared to Luminance (P<0.05), UV-opaque (P<0.001), Standard (P<0.05) and UV-transparent (P<0.001) filters (Fig. 3.b). The UV-transparent filter increased dry weights relative to Standard (P<0.05) and Solatrol (P<0.001), although there was no significant effect on dry weights when compared to Luminance (P>0.05, and UV-opaque (P>0.05, Fig. 3.b).

LEAF THICKNESS

The thickness of leaf two was increased in plants grown under the UV-transparent when compared to Solatrol (P<0.001), Luminance (P<0.001), UV-opaque (P<0.001), and Standard (P<0.001) filters (Fig. 4).

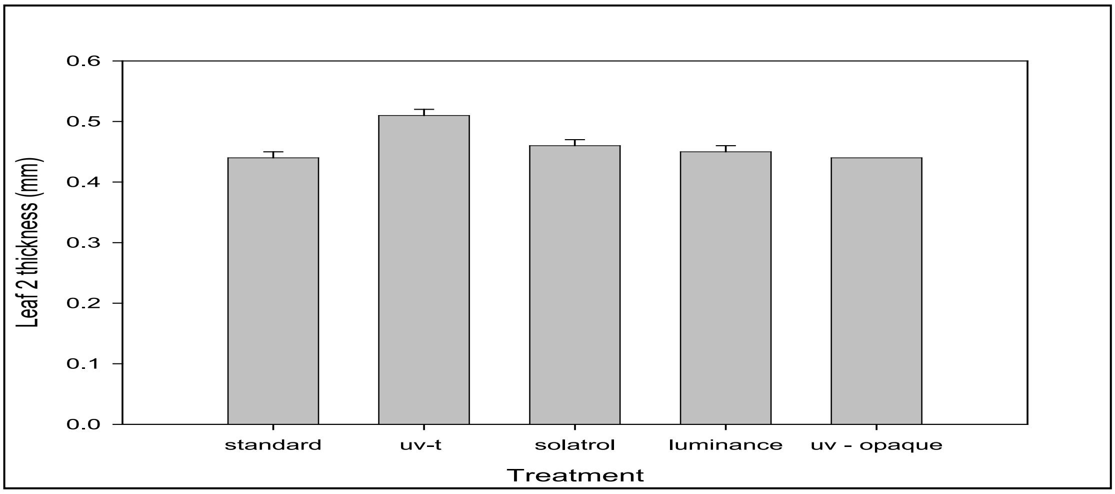


Figure 4. Effect of treatments on thickness of leaf 2 of propagation lettuce. Measurements taken at 14 days after treatment began. Each value is the mean ± S.E. of 12 replicates.

MECHANISM OF RESPONSE

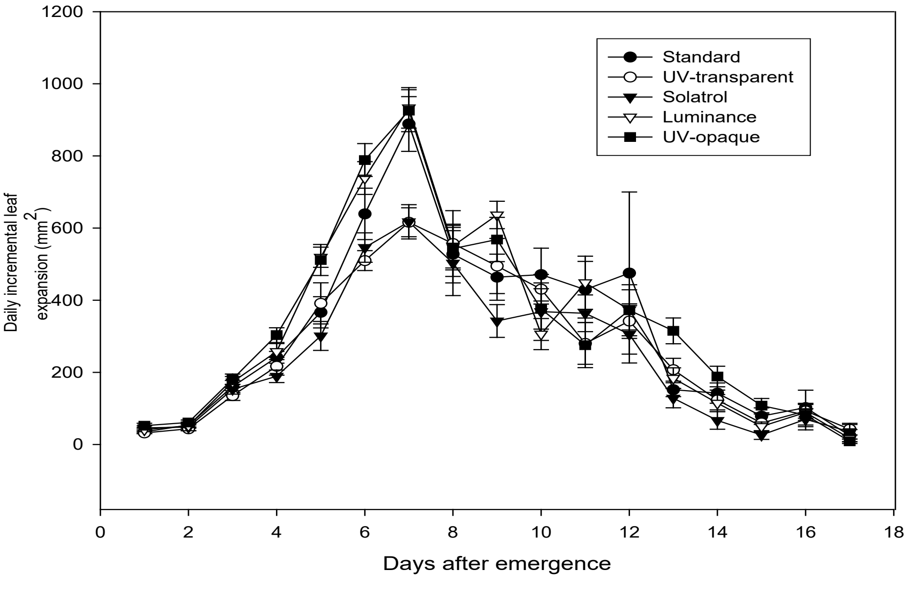
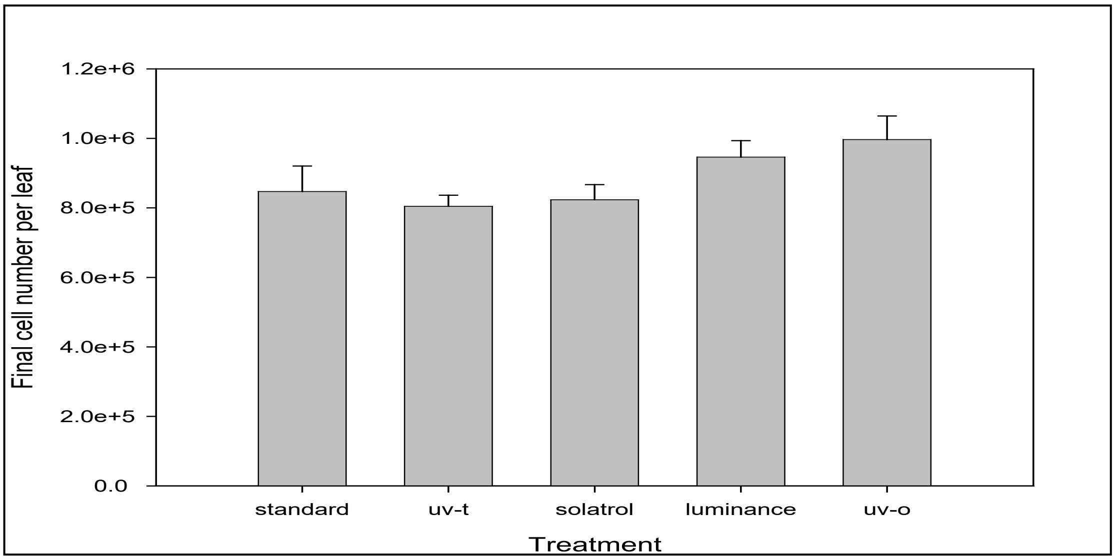


Figure 5. Effects of the treatments on the expansion of leaf 2 of propagation lettuce. Data presented as daily incremental leaf expansion ± S.E. for all treatments.

In a separate study, more detailed investigations of leaf expansion revealed that when compared to the Standard both the UV-transparent filters caused significant decreases in the expansion rate of leaf two during the period of maximum expansion (data not presented).

Reduced leaf expansion was not associated with any significant effect of filters on photosynthesis in leaf two over the 12-day experiment (data not presented). Also, in a destructive harvest of leaf two carried out after 20 days under the filters there was no significant difference between UV-transparent or Solatrol and Standard film in the total epidermal cell numbers per leaf in Standard (Fig. 6.a). By contrast, final epidermal cell area (Fig. 6.b) in both UV-transparent and Solatrol were significantly reduced compared to all other plastics.

a)



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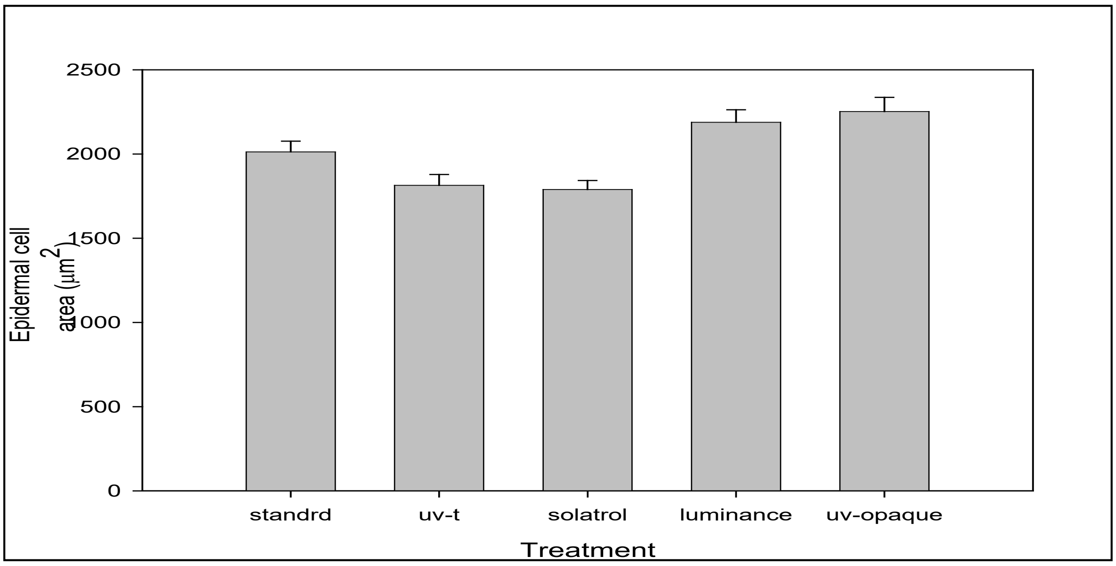


Figure 6. Effects of treatments on (a) final cell number and (b) final epidermal cell area per leaf in the second leaf of propagation lettuce. Leaf 2 was harvested 25 days following the beginning of treatments once growth had ceased. Each value is the mean of 15 replicates ± S.E.

FIELD TRIALS FRESH WEIGHTS

Fresh weights at time of harvest (Fig. 7) were significantly lower in Luminance treated plants than those from all other treatments. UV-transparent exhibited significantly increased fresh weights relative to both Luminance and Standard, and although fresh weight was increased by 9% when compared to UV-opaque plants, this was not statistically significant (Fig 7). There was no statistical difference between UV-transparent and Solatrol treated plants (Fig. 7), although UV-transparent plants did exhibit less variation in fresh weights than did Solatrol.

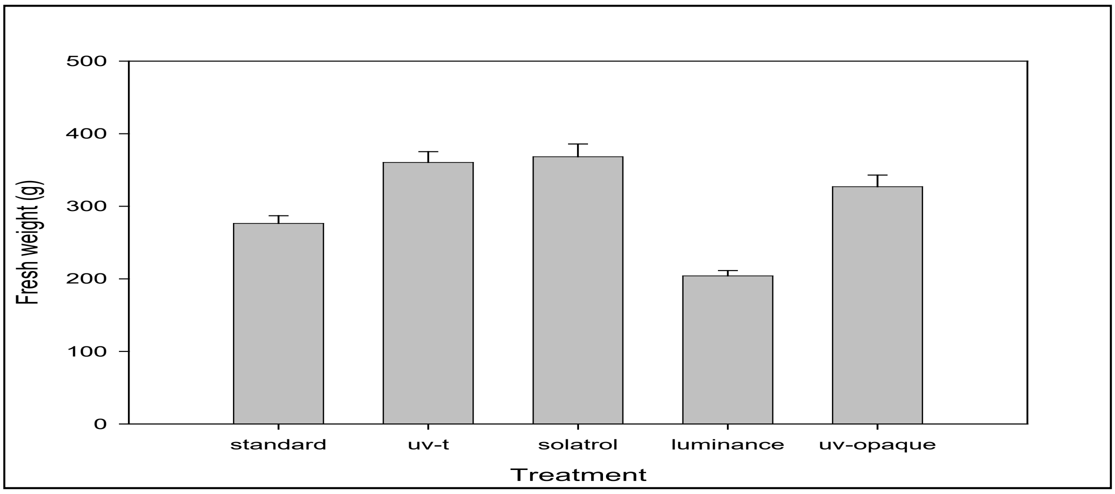


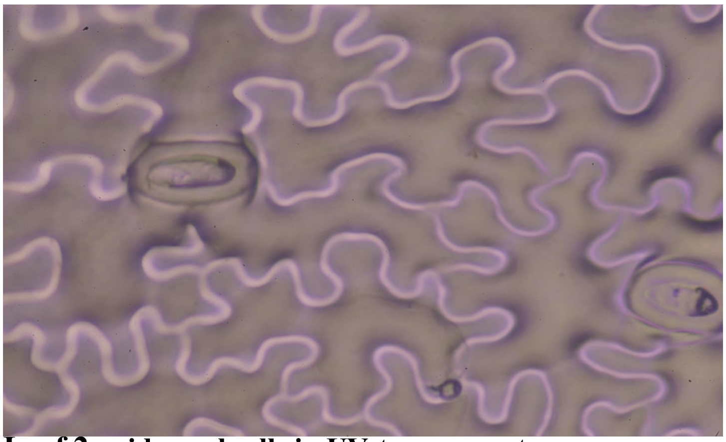
Figure 7. Effect of treatments on fresh weight of marketable lettuce taken from field trials. Harvest carried out 46 days after removal from filters. Each value is the mean + S.E. of at least 20 replicates.

Figure. 8. Crystal Heart lettuce at 14 days by which time the effects of the spectral filters were evident on plant morphology.

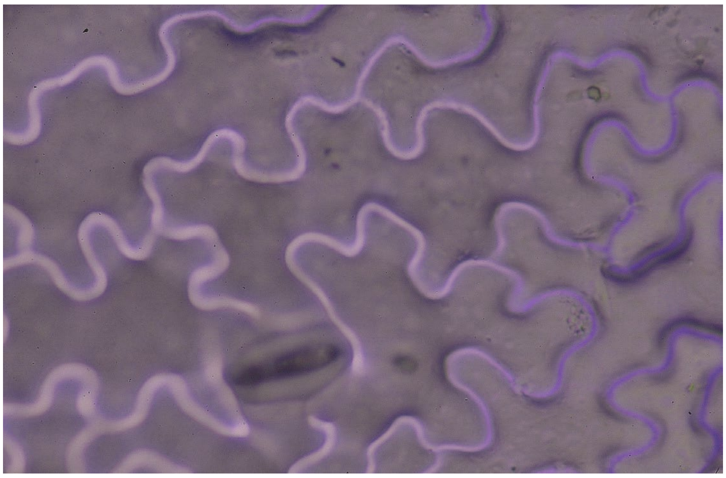
Discussion

What is clear from this series of studies in lettuce is that even limited exposure (14 days) to an altered light regime can rapidly alter whole plant morphology (Fig. 8). This can have significant effects on subsequent plant development that persist even when plants have been removed from the spectral filters and subjected to ambient field conditions (for a period of 46 days) in preparation for market sale (Fig. 9.a & Fig. 9.b).

The immediate effects of the filters were observed as rapid and significant reductions in the expansion rates of leaf two, seven days after the beginning of treatment, in both UV-transparent and Solatrol plants, when compared to Standard, Luminance and UV-opaque filters (Fig. 5). Further investigation revealed that this reduction in leaf expansion (in UV-transparent and Solatrol) led to decreased leaf areas at the time of sale (14 days) when compared to plants from the remaining three filters (Figs. 3.a. & Fig. 3.b). This reduction in leaf expansion gave a "shorter, stockier plant", which was a primary requirement of the growers. The reduction in leaf growth is not a function of reduced carbon fixation, but can be attributed to a reduction in epidermal cell area: there was no significant change in epidermal cell number in plants grown under UV-transparent and Solatrol (Figs. 6.a. & 6.b). The effect of the filters on cell expansion was also observable using light microscopy where epidermal cells are clearly elongated in plants grown under both Luminance and UV-opaque filters relative to UV-transparent and Solatrol (see below).



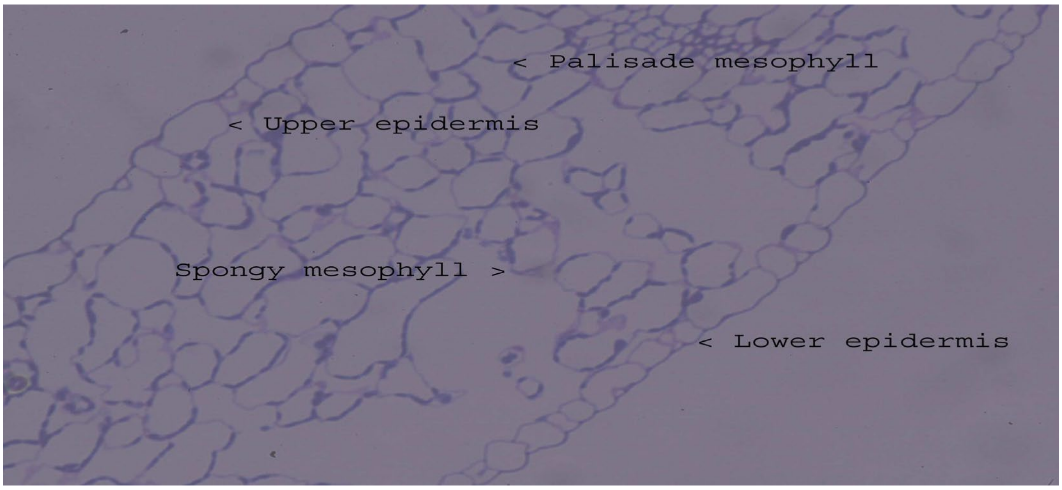
Leaf 2 epidermal cells in UV-transparent



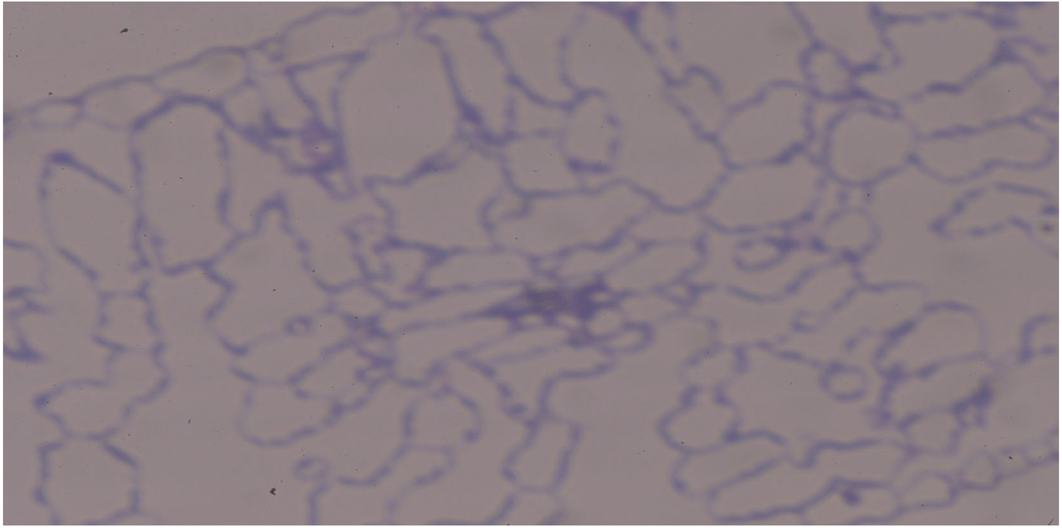
Leaf 2 epidermal cells in Luminance

The regulation of leaf expansion through changes in cell size is complex (Fry 1986). As well as changes in turgor (there is no evidence of altered water relations in plants grown under the spectral filters), cell wall extensibility is regulated by several enzymes, the details of which are outside the remit of this report (for review see Fry, 1986). However, further investigation into changes in the activity of those enzyme(s) in response to altered light regimes may be warranted in future studies, since identifying such key enzyme(s) could provide investigators with a rapid screening method for the evaluation of future growth regulating filters.

A well-recognised adaptation of many plant species to changing environmental conditions (e.g. increases in photosynthetically active radiation) is to generate additional layers of palisade mesophyll cells. Leaves exposed to relatively high light conditions (e.g. the UV-transparent filter) are thicker because they contain more rows of palisade mesophyll than do leaves of the same plant grown under lower light conditions (e.g. UV-opaque). This is because light is able to effectively penetrate multiple layers of palisade mesophyll, allowing all layers to photosynthesise efficiently. Such a response was observed in lettuce grown under the UV-transparent filter (see below) and was identified as a desirable trait by the growers. It may also have aided in the plants early adaptation to ambient conditions in the field trials, leading to improved long-term performance of the crop (Figs. 9.a. & 9.b).



Cross section of leaf 2 of lettuce in Luminance



Cross section of leaf 2 of lettuce in UV-transparent

The purpose of this study was to identify a plastic(s) that produces lettuce at the second leaf stage (point of sale) that is characterised by shorter, thicker and mechanically stronger leaves, and that subsequently performs well when planted out (see consultants report at the end of this section). Our preliminary conclusions suggest that either UV-transparent or Solatrol filters meet the growers criteria and further field trials in year two and three of the project will seek to clarify these findings.

Figure. 9.a. Summer 2003 propagation lettuce field trial (UV-transparent treatment).

Figure. 9.b. Summer 2003 propagation lettuce field trial (Luminance treatment).

Lettuce consultant report

Objective: To compare growth of iceberg lettuce plants under five tunnel coverings.

1. Standard
2. U.V. transparent
3. Solatrol
4. U.V. opaque
5. Luminance

Trials commenced in May. Plants were supplied by a commercial propagator in 4.2cm blocks. Plants were approximately 7-10 days old on delivery and were left in the tunnels for 14 days. Tunnels 2 and 3 consistently showed better results with the plants being sturdier, stronger, and having better root development.

In the last batch it was decided to see if this growth continued outside after planting therefore a plot was planted from each tunnel.

Plants were planted out on August 21st and were then grown under normal commercial conditions.

A sample of each batch was cut on September 29th 2003.

At this stage tunnels 2 and 3 were still showing a better performance. However, because of the onset of frost, rather than crop maturity, harvesting took place. Plots from tunnels 2 and 3 produced the most even marketable heads, tunnel 4 was by far the poorest with no marketable heads.

The results of the effects of each tunnel were clear even in a short trial, a longer trial throughout the season would be of benefit to see if the differences were maintained.

Mr John Sykes   Signature:…………………………...

Literature cited

Akiyama T. & Pillai M.A. (2001) Molecular cloning, characterization and in vitro expression of a novel endo-1,3-small beta, Greek-glucanase up-regulated by ABA and drought stress in rice (*Oryza sativa* L.). *Plant Science* **6**, 1089-1098.

Cosgrove D.J. (2001) Plant cell walls: Wall-associated kinases and cell expansion. *Current Biology* **14**, R558-R559.

Cosgrove D.J. (1993) Water uptake by growing cells: an assessment of the controlling roles of wall relaxation, solute uptake and hydraulic conductance. *International Journal & Plant Science* **154**, 10-21.

Fry S.C. (1986) Cross-linking of matrix polymers in the growing cell-walls of angiosperms. *Annual Review of Plant Physiology and Plant Molecular Biology* **37**, 165-186.

Peters W.S, Hagemann W. & Tomos A.D. (2000) What makes plants different? Principles of extracellular matrix function in `soft' plant tissues. *Comparative Biochemistry and Physiology - Part A: Molecular & Integrative Physiology* **2**, 151-167.

Acknowledgements

All plants for this study were supplied by The Crystal Heart Salad Company, Gilberdyke, East Yorkshire.

Part 2. Propagation brassicas : Cabbage and Cauliflower

Introduction

Horticultural brassicas (Brussels sprouts, cabbage, broccoli and cauliflower) are grown on about 32,500 hectares (MAFF Basic Horticultural Statistics Census, 2001) and are important crops for a large number of growers. Most of these crops are established from modules grown under protected structures for 6-8 weeks, depending on the time of year, before being machine planted.

The production of module plants has become a specialist business for several companies and there is a need to develop lower cost growing methods whilst not compromising plant quality. Carefully controlled conditions are required to optimise germination and early emergence for the first 1- 2 weeks after sowing. For outdoor crops, uniform emergence of drilled crops is known to influence crop uniformity at harvest. Therefore, uniform emergence of seeded crops in modules could also be critical to maximise plant establishment and the percentage of plants that are cut at the first harvest.

From the cotyledon stage onwards, plants must be grown under cooler tougher conditions to ensure that leggy growth is avoided and this is achieved by a combination of careful temperature control and by liquid feeding. Plants must not become leggy as this can encourage disease development. Furthermore, if tissue is soft, brassicas can be damaged by pre-plant drenches applied for cabbage root fly control and also during the planting operation.

There is potential to use more ventilated structures for raising brassica plants. This would release glasshouse space for other uses or increase output if the plants were grown in glasshouses for a shorter period before being moved out into other cheaper structures.

The aim of the 2003 work was to investigate the effects of using the five spectral filters on the growth and development of module raised plants. Both cauliflowers and cabbage were used. Plants were moved out into the tunnels after just 10-14 days and were compared to other trays of plants, which remained in the glasshouse for an additional 3 weeks.

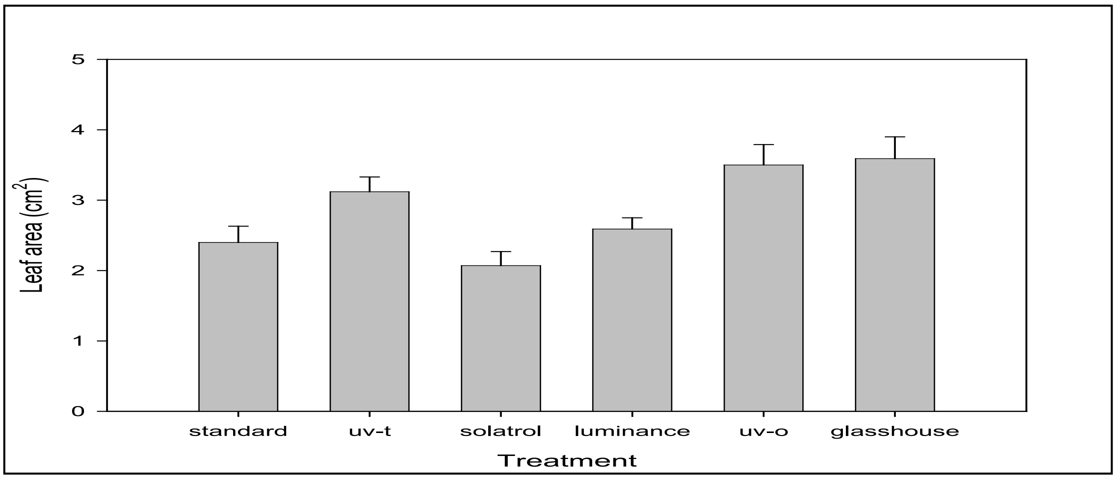
Results (Cabbage – cv. Summer Green)

LEAF AREA AND THICKNESS

Total leaf area was significantly greater in glasshouse grown plants than in all the plastics except UV-opaque (Fig. 1.a). Within the plastics, Solatrol reduced total leaf area when compared to Luminance, UV-opaque, and UV-transparent, but not the standard film (Fig 1.a).

Leaf thickness in the smallest leaf (at the time of harvest) was significantly lower in Standard when compared to all other treatments ($\geq P<0.01$, see Fig. 1.b). There were no significant differences between the remaining treatments. In the largest leaf (at the time of harvest) thickness was significantly greater in glasshouse-grown plants than in all the plastics except Luminance (Fig. 1.c)

a)



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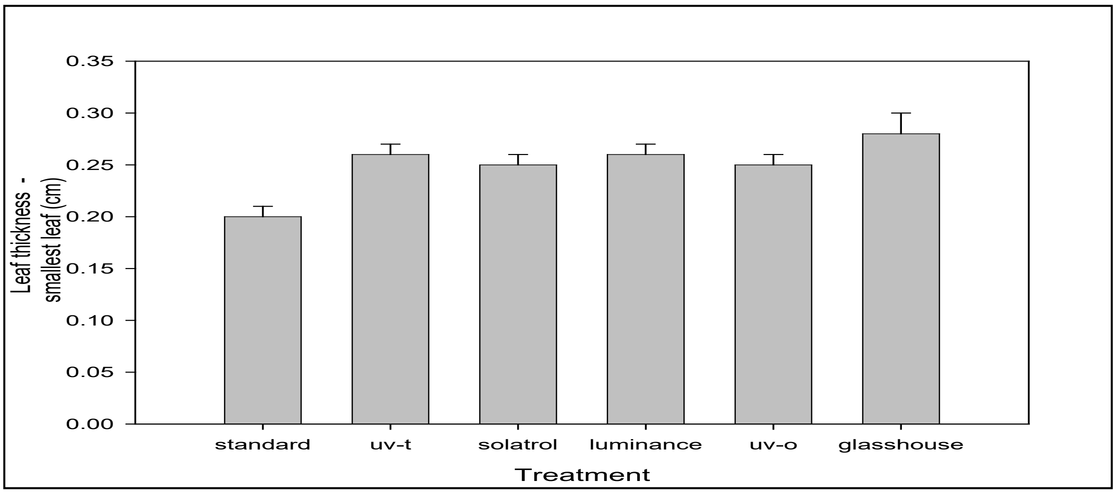


c)

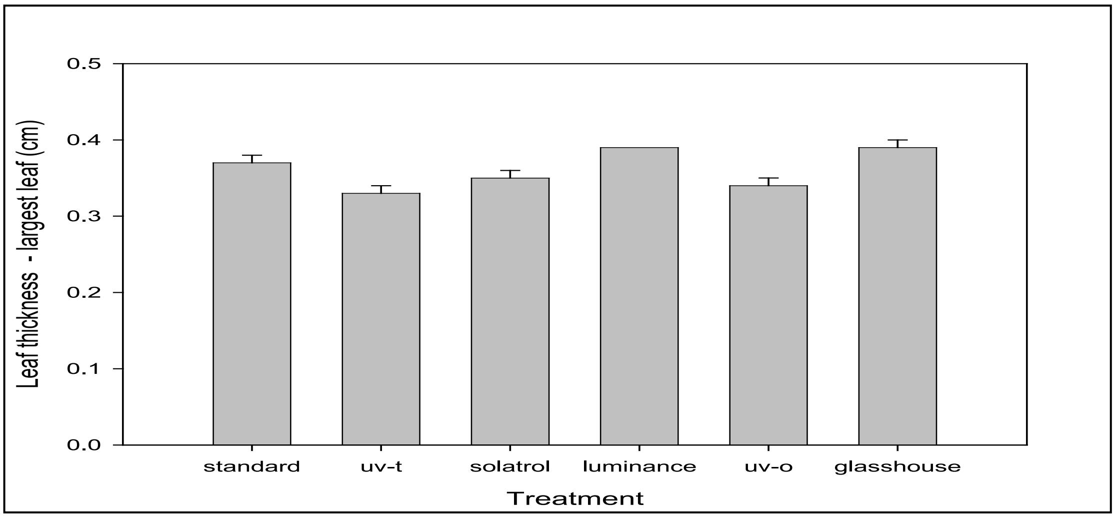


Figure 1. Effect of treatments on (a) total leaf area (b) leaf thickness (smallest leaf) (c) leaf thickness (largest leaf) in cabbage. Each value is the mean ± S.E. of 20 replicates.

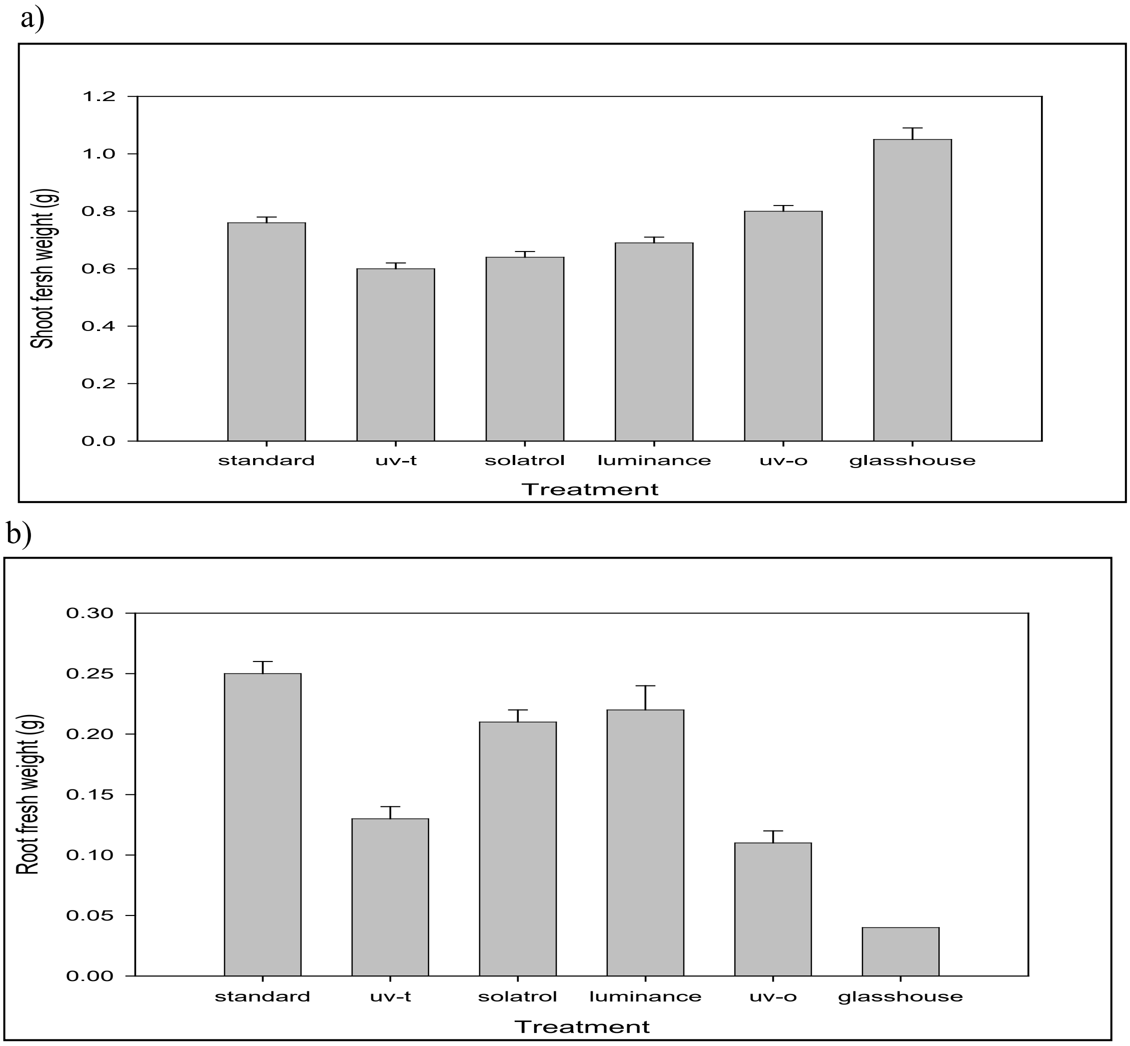


Figure 2. Effect of treatments on (a) plant (shoot) fresh weight (b) root fresh weight and (c) plant fresh weight in cabbage field trials. Each value is the mean ± S.E. of 20 replicates.

FRESH WEIGHTS

Glasshouse treated plants showed a highly significant increase in shoot fresh weight (Fig. 2.a) but a highly significant reduction in root fresh weight (Fig. 2.b) relative to all the plastics. Between plastics there were no significant differences in shoot fresh weight, but root fresh weights in UV-transparent, Solatrol, UV-opaque and were are decreased compared to the standard film (Fig. 2.b).

FIELD TRIALS

There were no significant effects of treatments on plant fresh weights in field trials (Fig. 3).

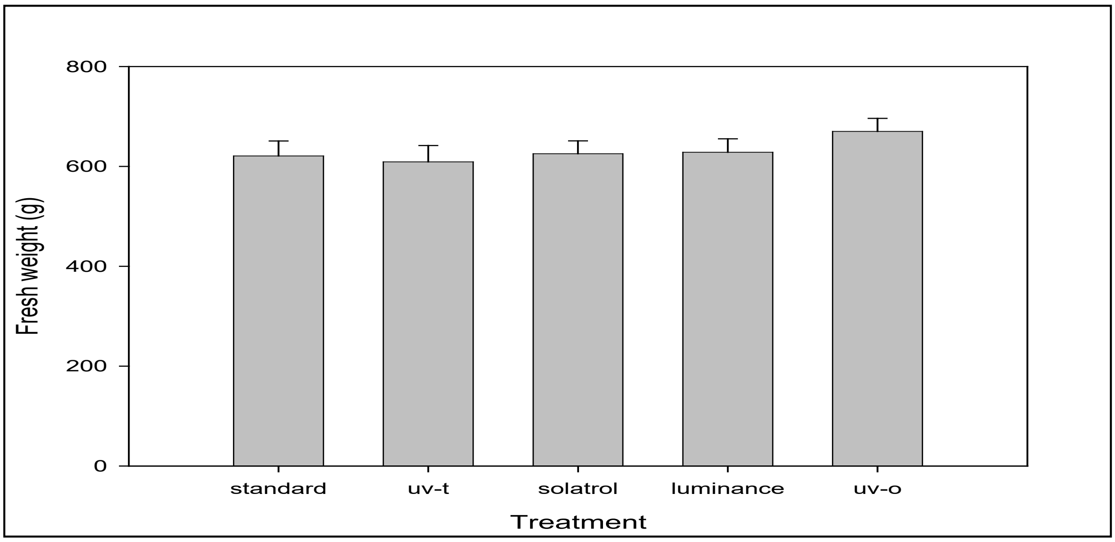


Figure 3. Effect of treatments on plant fresh weight in cabbage field trials. Each value is the mean ± S.E. of 20 replicates.

Results (Cauliflower – cv. Thasca)

LEAF AREA AND THICKNESS

Total leaf area was higher in glasshouse grown plants than in all the plastics (Fig. 4.a.). At the time of harvest the thickness of the smallest leaf (approximately 10 days post emergence) in the Standard filter was significantly reduced relative to the remaining five treatments except Solatrol ($\geq P<0.05$, see Fig. 4.b). There were no other significant differences. The thickness of the largest leaf (at the time of harvest) was significantly greater in glasshouse treated plants than all plastics except Luminance (Fig. 4.c).

SHOOT / ROOT FRESH WEIGHTS

Glasshouse treated plants exhibited a highly significant increase in plant fresh weight relative to the remaining five treatments ($P<0.001$) (Fig. 5.a). Plants grown in the glasshouse had significantly greater root fresh weights than all the plastics (Fig. 5.b). There was no significant difference between root fresh weights in UV-transparent, Solatrol and Luminance treatments, but both Standard and UV-opaque filters had lower root fresh weights than all other treatments (Fig. 5.b).

FIELD TRIALS FRESH WEIGHTS

Fresh weights were significantly increased in UV-opaque relative all other plastics, and Solatrol significantly reduced plant fresh weights compared with all other plastics (Fig. 5.c).

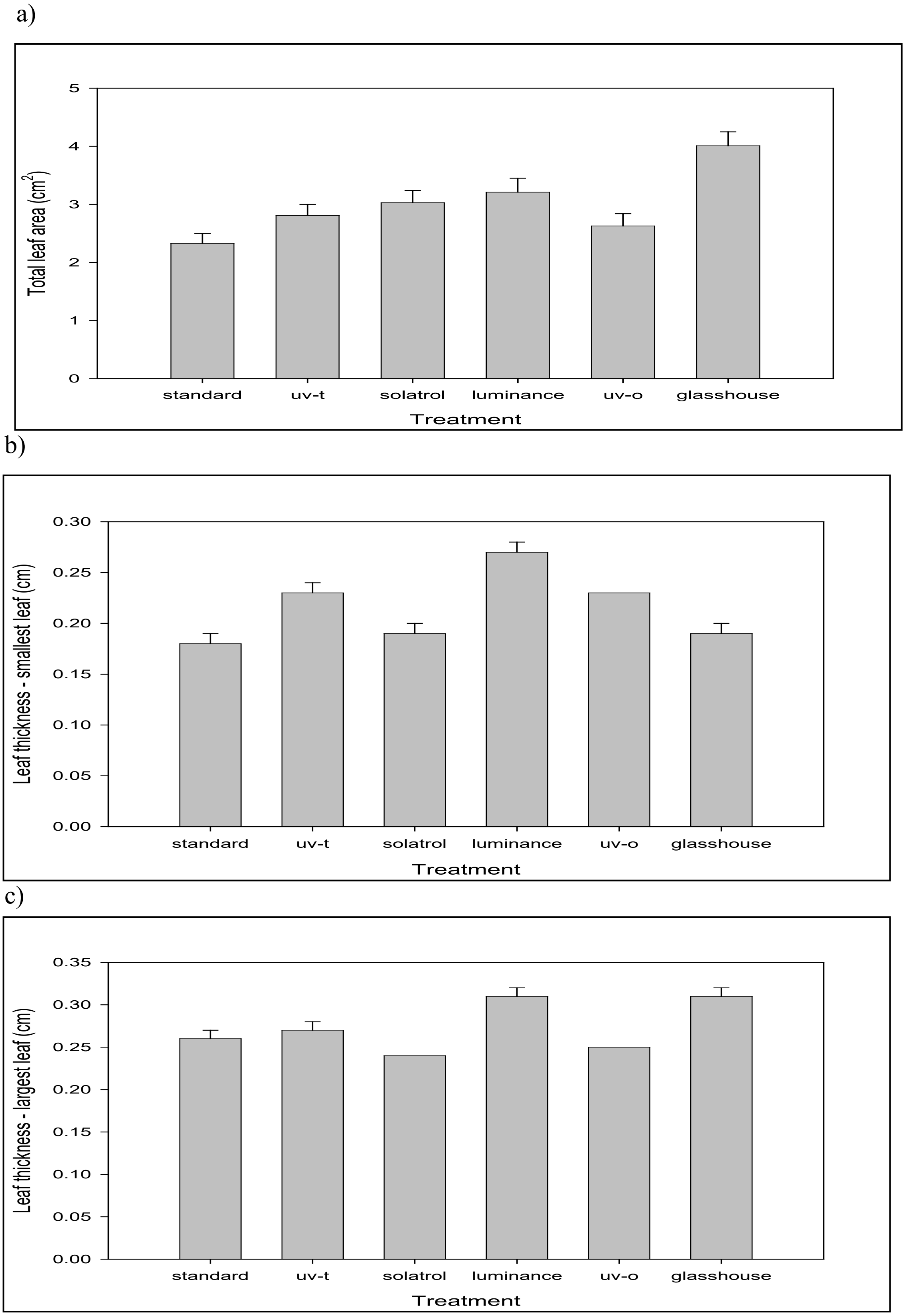


Figure 4. Effect of treatments on (a) total leaf area (b) leaf thickness (largest leaf) (c) leaf thickness (smallest leaf) in cauliflower. Each value is the mean ± S.E. of 20 replicates.

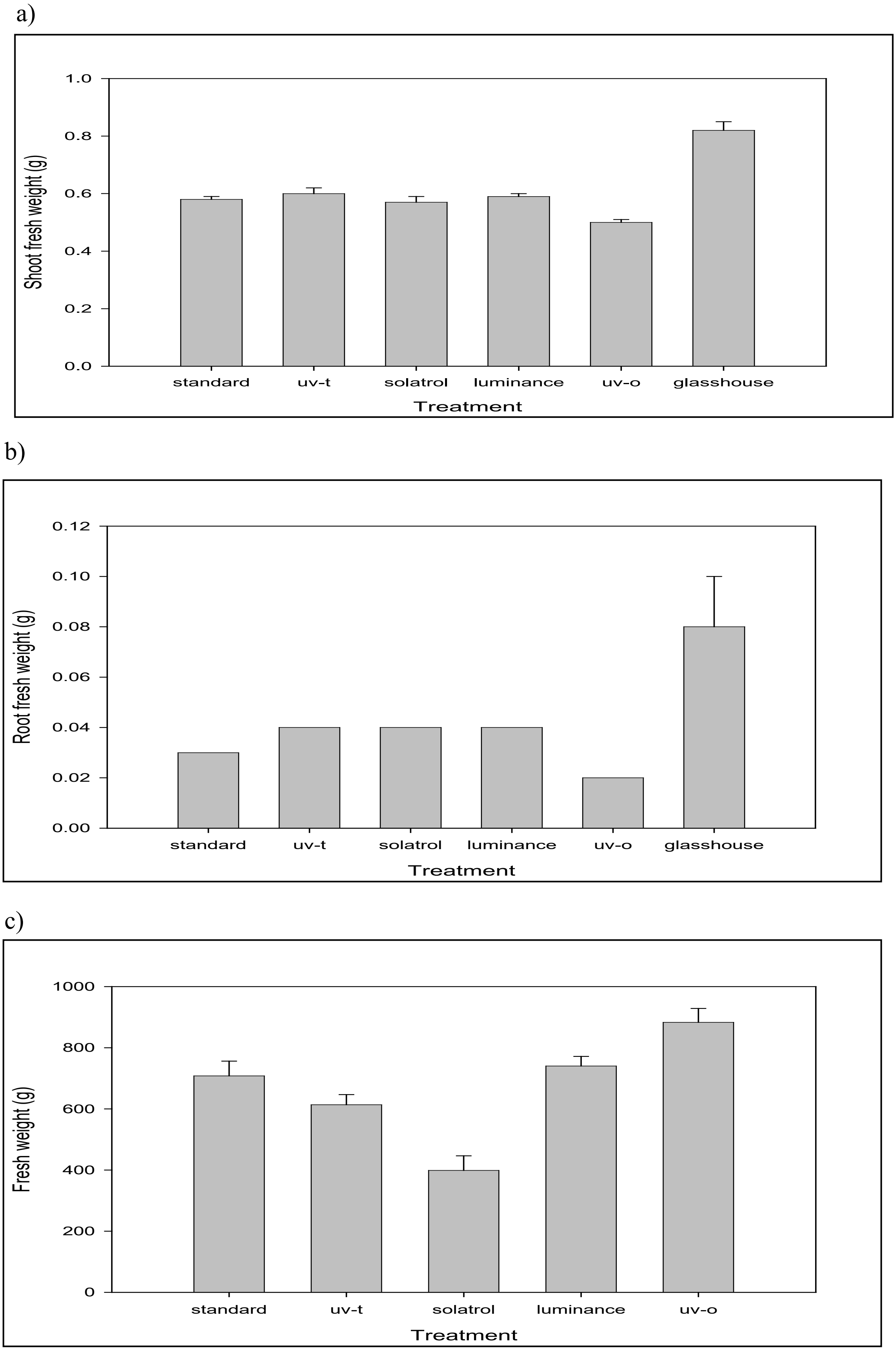


Figure 5. Effect of treatments on (a) plant fresh weight (b) root fresh weight and (c) plant fresh weight in cauliflower field trials. Each value is the mean ± S.E. of 20 replicates.

Discussion

The purpose of the first years study was to undertake preliminary investigations into the effects of the five spectral filters on brassica development. Of specific interest was the identification of a filter that altered plant physiology and morphology in such a way as to provide the propagator with a small, stocky plant and toughened vegetative tissue, so as to avoid disease development and mechanical damage caused by pre-plant drenches. A plant of this type might also be able to withstand stress at planting, possibly leading to faster establishment.

In the case of cabbage, results suggest that Solatrol would provide the shortest, stockiest plant with a relatively well-developed root system (see Figs. 1.a. and 2.b), although these morphological changes had no effect on final fresh weights in field trials (Fig. 3). However, preliminary visual assessments also suggests that propagating cabbage under Solatrol may also affect wax development on the cuticle, which could have consequences for both disease and pest resistance in the field (see Fig. 6).

With regards to Cauliflower, the Standard filter produced the shortest, stockiest plant, although root development was reduced (see Figs 4. & 5.b). UV- opaque also produced a short, stocky plant and leaf thickness was increased relative to Standard, Solatrol and Glasshouse grown plants, which could lead to beneficial changes in tissue strength (see Figs. 4.a. & 4.c). Furthermore, UV-opaque outperformed all other treatments in terms of terminal plant fresh weight in field trials (Fig. 5.c).

In conclusion, results from the first year's trials provide strong evidence that spectral filters can effect brassica development in economically beneficial ways. Further field investigations using three plantings throughout the 2004 growing seasons should be undertaken in order to determine whether the observed effects at the propagation stage lead to a more marketable crop. Of more particular interest would be any effects on curd initiation in cauliflower. We should also consider including broccoli as this crop accounts for 22% of all brassicas grown to ensure that any changes in whole plant physiology does not compromise yield at harvest. If stockier plants are produced, but there is an effect on time to harvest, then this will have to be carefully considered.

Figure 6. Colour change observed in cabbage (summer green) grown under Solatrol (left) and Standard (right).

Acknowledgements

All plants for this study were supplied by Westhorpe Flowers and Plants, Benington Boston, Lincs.

Part 3. Leafy Salads

Introduction

Lettuce and leafy salad crops are grown for whole head production and for inclusion in mixed leaf pillow packs over as long a season as possible. To maximise quality and prolong shelf life, it is essential that foliage is free from pest and disease contamination.

Production under plastic will provide potential benefits include faster growing cycles, ability to reduce pest contamination and better continuity scheduling. Protecting the crop from adverse weather could also help maintain leaf quality.

In this project, two different coloured varieties of Swiss chard were direct drilled, and red lettuce Lollo rosso and Frisee endive were transplanted following propagation in a glasshouse. The Lollo rosso was included to determine if any of the plastics would either enhance, or have a detrimental affect, on leaf characteristics and coloration. The endive was included to determine if any of the plastics would affect the development of the flower stalk and subsequent bolting.

Results

LOLLA ROSSA

PLANT COLOUR CHANGE

The most marked effects of the different films on this crop were on pigmentation. There were clear differences in plant colouration between treatments (see Figs. 1 & 2), ranging from very little obvious pigmentation in UV-opaque to very strong pigmentation in UV-transparent (see Figs. 1 & 2).

Figure 1. Lollo rosso. Samples were harvested 39 days after beginning of treatment and were typical of all replicates.

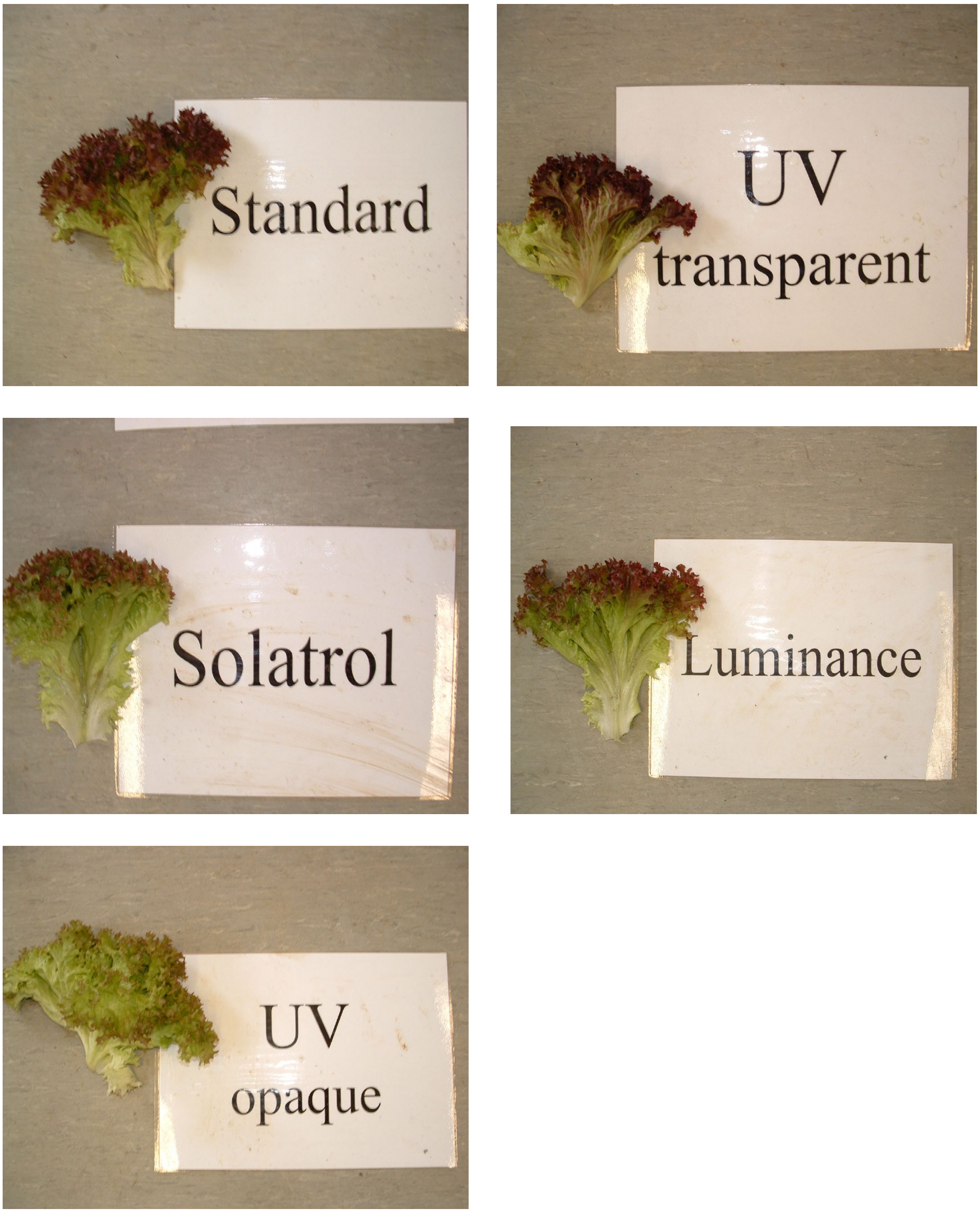
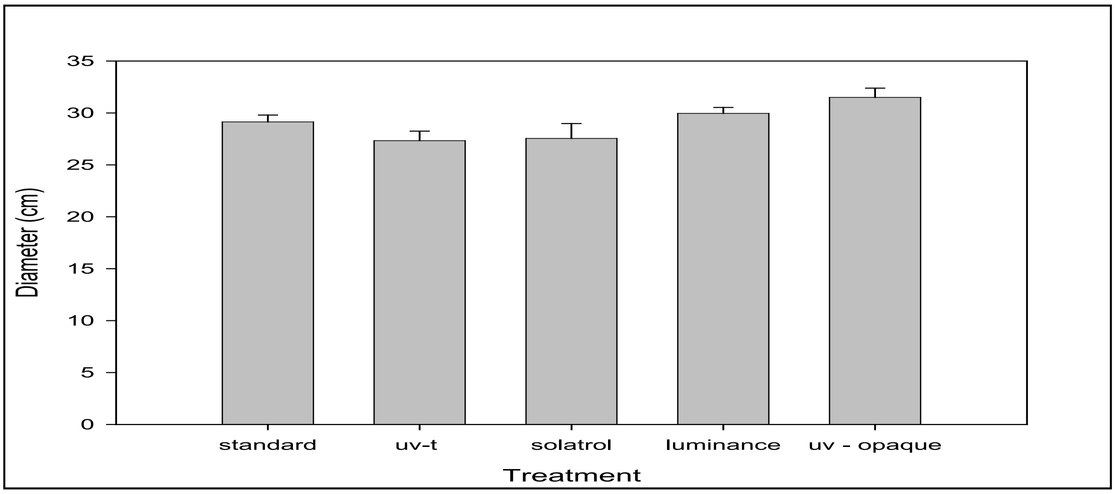


Figure 2. Individual leaves of Lollo rosso. Samples were harvested when they became marketable and were typical of all replicates.

PLANT MORPHOLOGY

Plant diameter and plant height were measured at the point of harvest. Plant diameter was significantly increased under UV-opaque when compared all other plastics except Luminance (Fig. 3.a). There were no significant effects of treatments on plant height (Fig. 3.b).

a)



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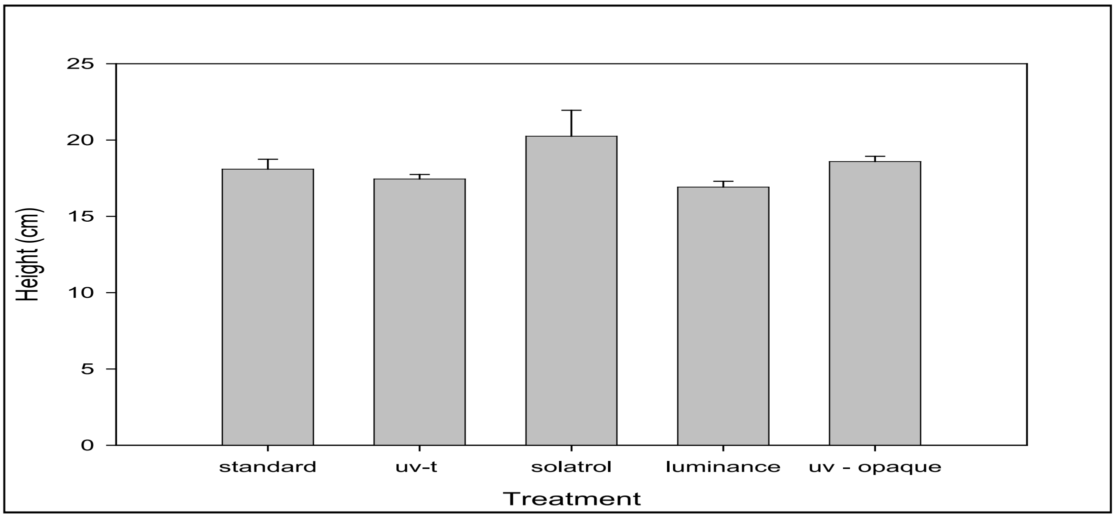
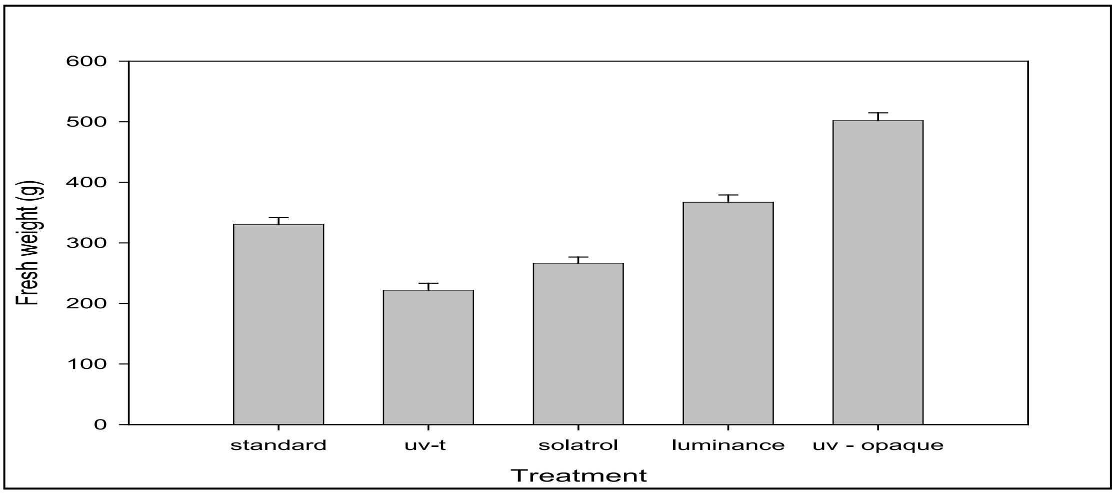


Figure 3. Effect of treatments on (a) plant diameter and (b) plant height in Lollo rosso. Each value is the mean ± S.E. of 20 replicates.

PLANT FRESH AND DRY WEIGHTS

Plant fresh weight was significantly higher in UV-opaque and significantly lower in UV-transparent than all other treatments (Fig. 4.a). Both UV-transparent and Solatrol filters significantly reduced plant dry weight compared to the standard, the effects of Luminance and UV-opaque were not significant (Fig 4.b).

a)



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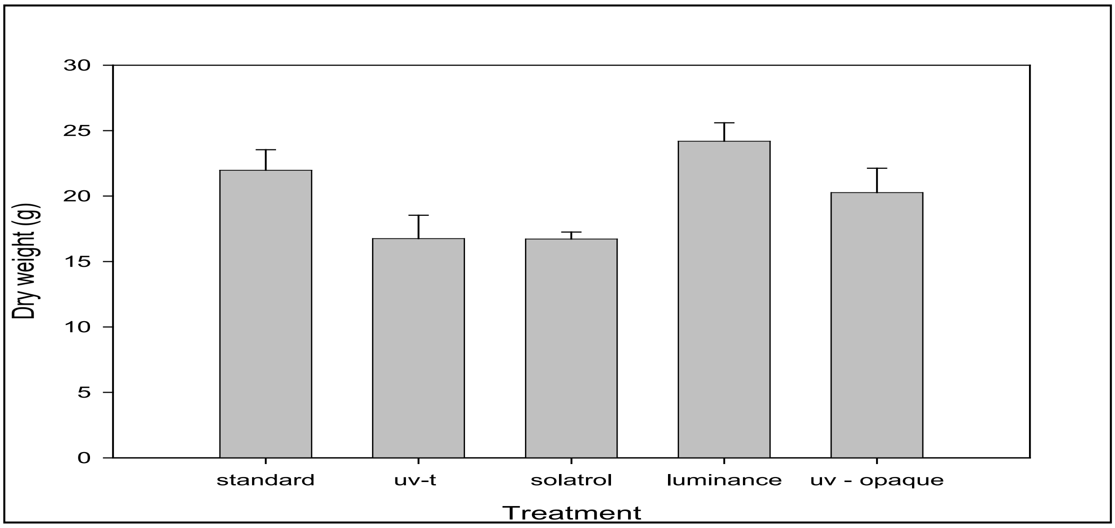


Figure 4. Effect of treatments on (a) plant fresh weight and (b) plant dry weight in Lollo rosso. Each value is the mean ± S.E. of 20 replicates.

Results

ENDIVE

LEAF AREA AND THICKNESS
Both Standard and UV-transparent treatments exhibited significantly increased leaf areas when compared to the remaining four treatments (Fig. 5.a). There was a highly significant reduction in leaf area in the field compared to all plastics except Solatrol (Fig. 5.a). There was no effect of treatments on the thickness of the newest leaf (data not presented) or of the oldest leaf, although Standard did increase leaf thickness of the latter when compared to Field (Fig. 5.b)

PLANT FRESH WEIGHT
Field significantly reduced plant fresh weights when compared to all plastics except Solatrol (Fig. 5.c). Fresh weights under the standard film were significantly higher than under Solatrol or in the Field, but not compared to UV-opaque or UV-transparent (Fig.5.c).

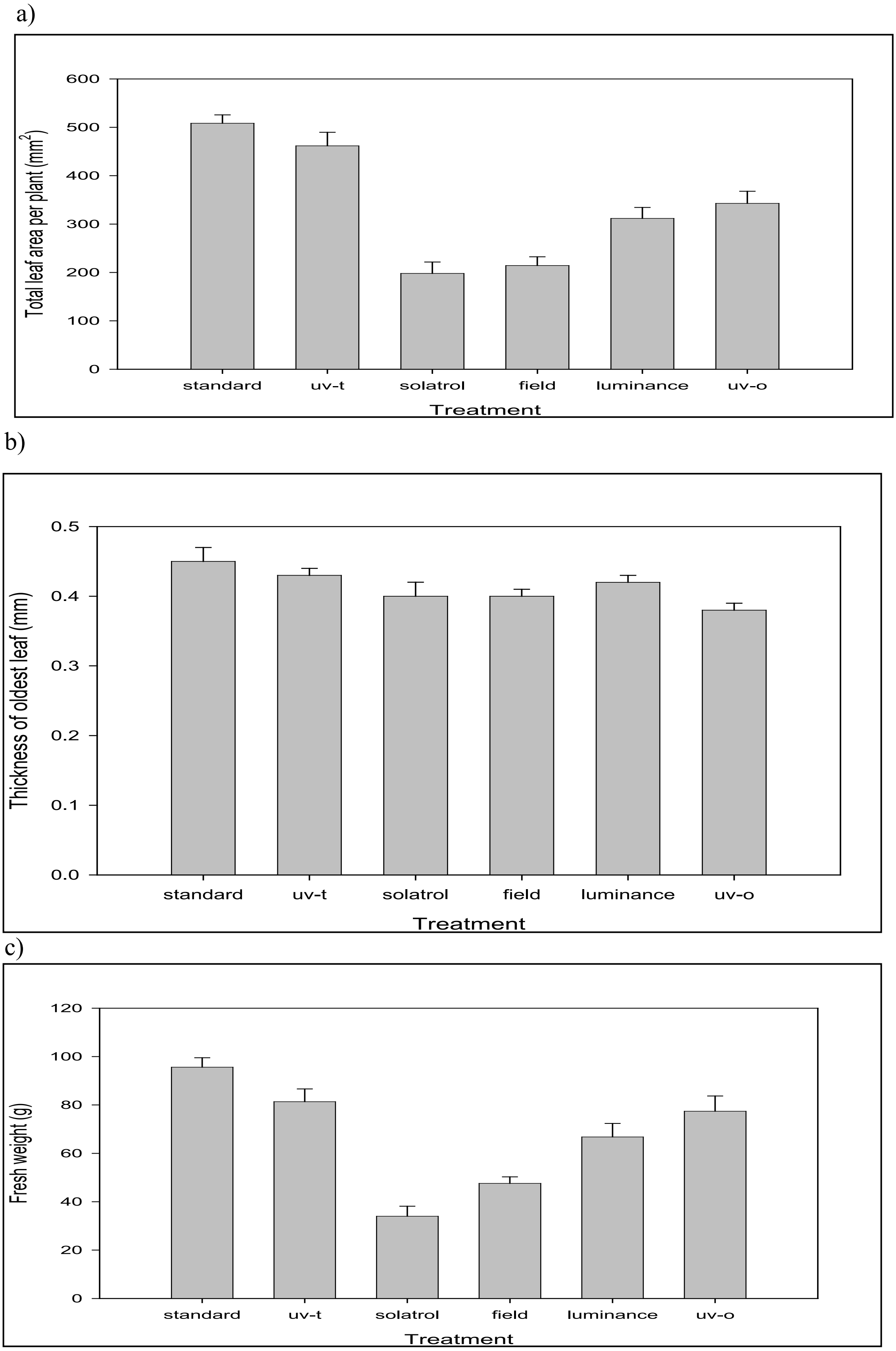


Figure 5. Effect of treatments on (a) plant total leaf area and (b) leaf thickness of the newest leaf and c) plant fresh weight in Endive. Each value is the mean ± S.E. of 25 replicates.

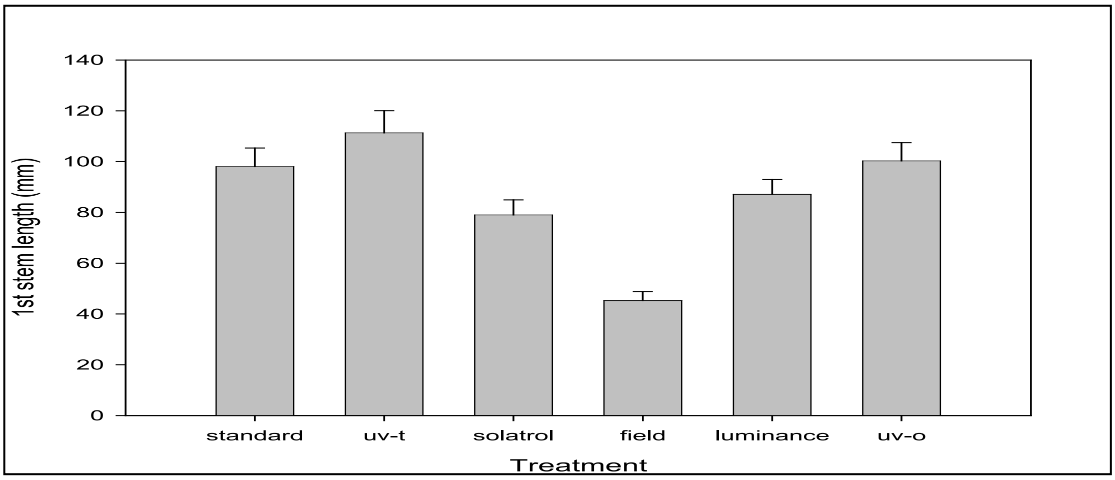
Results

SWISS CHARD

PLANT MORPHOLOGY

There were no significant effects of the six treatments on the number of leaves produced (data not presented). Petiole length (of the 1st leaf) was significantly reduced in the field compared to all five filters (Fig. 6.a). In addition, plants produced under UV-transparent film exhibited significantly increased petiole length relative to Solatrol, and Luminance, but not compared to UV-opaque or standard treatments (Fig. 6.a). Leaf thickness (Fig 6.b) was significantly lower and leaf area (Fig 7.a) was significantly higher under standard film than in the field, but there were no other significant effects of treatments. There was a significant reduction in plant fresh weight in Field grown plants when compared to all the plastics (Fig. 7.b). There was no significant difference in fresh weights between the five filter treatments (Fig. 7.b).

a)



b)

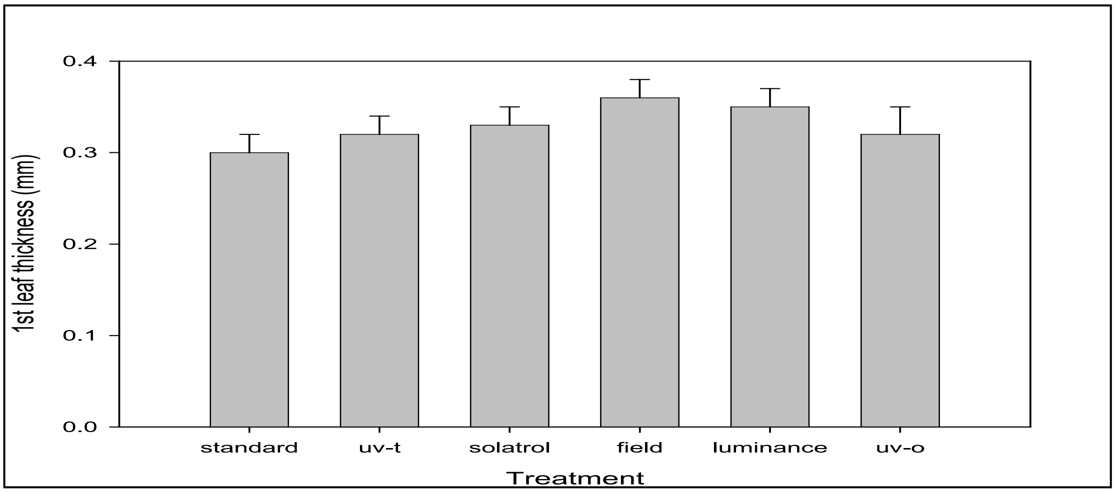
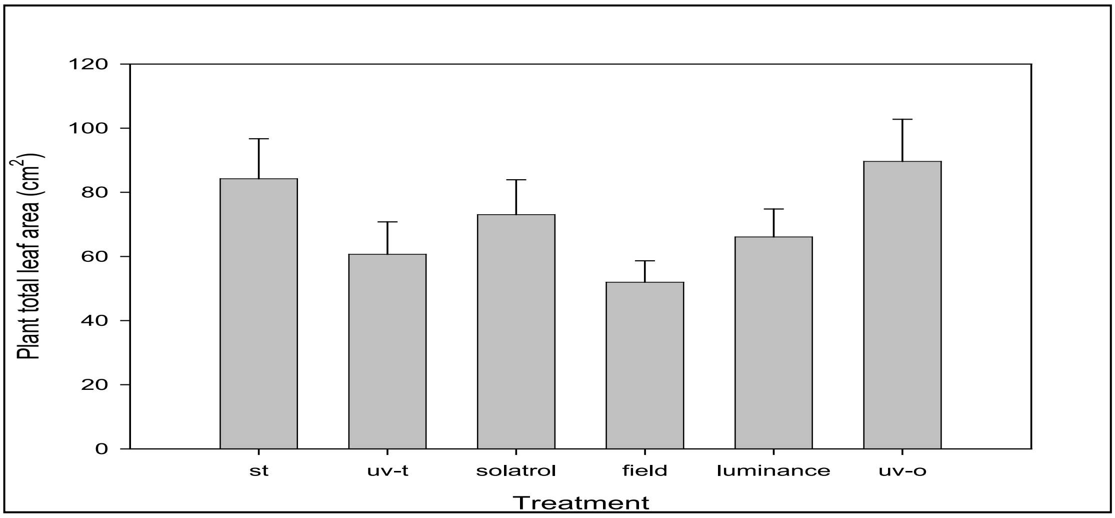


Figure 6. Effect of treatments on (a) the length of the petiole in the 1st leaf and (b) 1st leaf thickness in Swiss chard. Each value is the mean ± S.E. of 25 replicates.

a)



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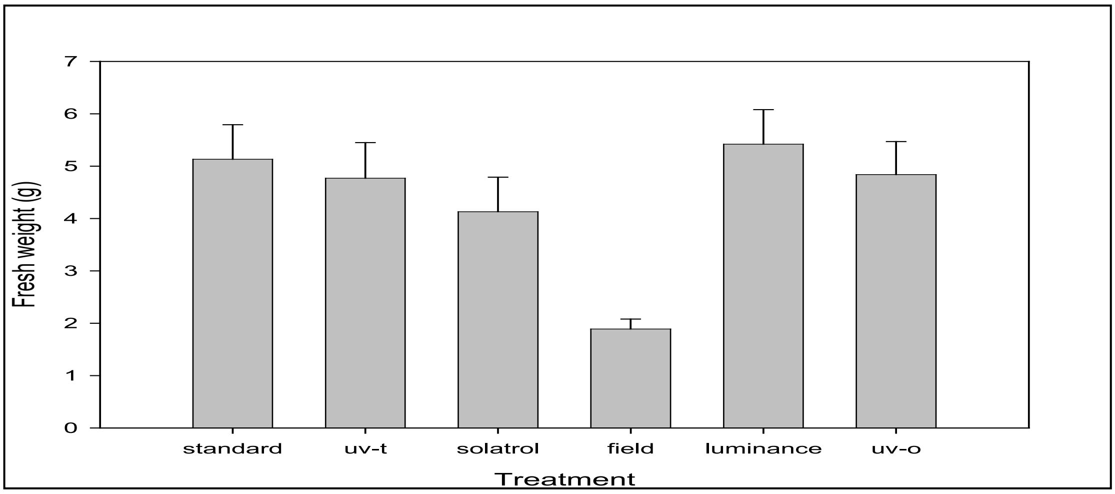


Figure 7. Effect of treatments on (a) total leaf area and (b) total plant fresh weight in Swiss chard. Each value is the mean ± S.E. of 25 replicates.

Discussion

The purpose of the first year's preliminary investigations was to determine if the spectral filters could improve crop quality, appearance and/or yield.

Lollo rosso is primarily used in mixed leaf pillow packs and so the visual properties of the crop are of great importance. A high level of red pigmentation in leaf tissue is desirable as are low levels of visual damage caused by pests and disease. Both Standard and UV-transparent filters produced visually increased levels of pigmentation in Lollo rosso when compared to the other treatments (see Figs. 1 & 2). The colouration under Solatrol was almost brown, compared to more vivid colours exhibited by the other treatments. Determining the effect of a range of plantings and weather conditions requires further work in 2004. Standard also produced plants with higher fresh and dry weights when compared to UV-transparent which, in conjunction with the relatively high levels of pigmentation, is a highly desirable trait (see Figs. 4.a & 4.b).

Endive is also primarily used in leafy salad packs and so the visual properties of the crop including leaf habit, natural blanch and crop weight at the time of harvest are important. Crop productivity was observed to vary greatly under the filters. Both Standard and UV-transparent produced increases in total leaf areas, and leaf thickness and plant fresh weights, especially when compared to Solatrol and conventionally produced field plants (see Figs. 5.a., 5.b. and 5.c). Further investigations in the second year's trials will seek to clarify whether these productivity increases are accompanied by beneficial changes in crop quality, particularly the level of natural blanching of the leaf stems. In addition, any effects on the plants' susceptibility to bolting from early plantings will be required.

Results from Swiss chard are somewhat less persuasive than those for Lollo rosso and endive. What is clear from this study is that plant fresh weights were significantly reduced in conventionally produced field plants when compared to all five filters (Fig. 7.b). While results point to increased crop productivity in both Standard and UV-opaque there was a high degree of variability under all five filters (see Figs. 7.a and 7.b). Therefore, further studies are required to clarify the potential economic benefits of substituting traditional field production with filters.

Results from the first season's trials suggest that crop productivity can be significantly improved by growing under either the Standard or UV-transparent filter. Furthermore, these improvements might be of sufficient economic benefit to offset the increase in cost of switching production from conventional field production. Although detailed investigations of the effects of spectral filters on the levels of pest and disease were outside the remit of the first season's study, they should form an important component of future trials given their importance for the marketability of the product.

Part 4. Bedding plants

Introduction

Although the bedding plant sector has enjoyed strong growth in the past four years (~7% year on year) and still remains one of the most profitable horticultural sectors (approx. £70k per acre, personal communication Mr Stuart Coutts), margins are now coming under increasing pressure as large retail outlets attempt to drive down prices. While traditionally the industry has relied heavily on glasshouse production, before moving its crop outdoors, this new market pressure may encourage growers to look for more cost effective alternatives to glass. One possibility is to employ large-scale spectral filters, which not only provide protection from the environmental (e.g. hail damage), but may also alter plant development in economically beneficial ways.

Preliminary studies in May 2003 with Petunia, Impatiens, Dianthus, Geranium and Antirrhinums indicated that were distinct differences between treatments in terms of plant height, leaf colour and time to flowering. These early assessments were quite subjective but differences were recorded photographically (e.g. Figure 1). These results prompted more details studies that focused on Antirrhinum in the early summer and Pansy in late summer / autumn.

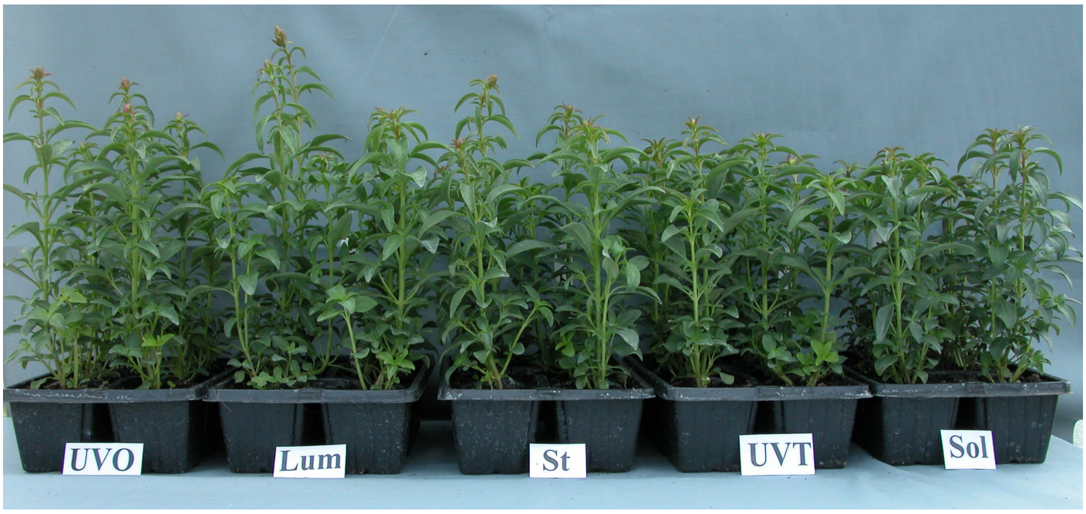


Figure 1. Effects of filters on plant height in Pansy and Antirrhinums.

Results

ANTIRHINUMS

One of the main effects of treatments was the highly significant delay in flowering in Solatrol when compared to all other treatments (Fig. 2.a). Plant height was significantly reduced in UV-transparent relative to Luminance and UV-opaque treatments, although there was no effect when compared to Solatrol and Standard (Fig. 2.b). The Solatrol filter significantly reduced the number of flowers per plant when compared to Luminance, UV-opaque and Standard, although there was no effect relative to UV-transparent (Fig. 2.c). Solatrol also significantly reduced terminal bud length relative to Luminance and UV-opaque only (Fig. 3.a). Finally, in UV-transparent root dry weight was significantly increased compared to all treatments (Fig. 3.b).

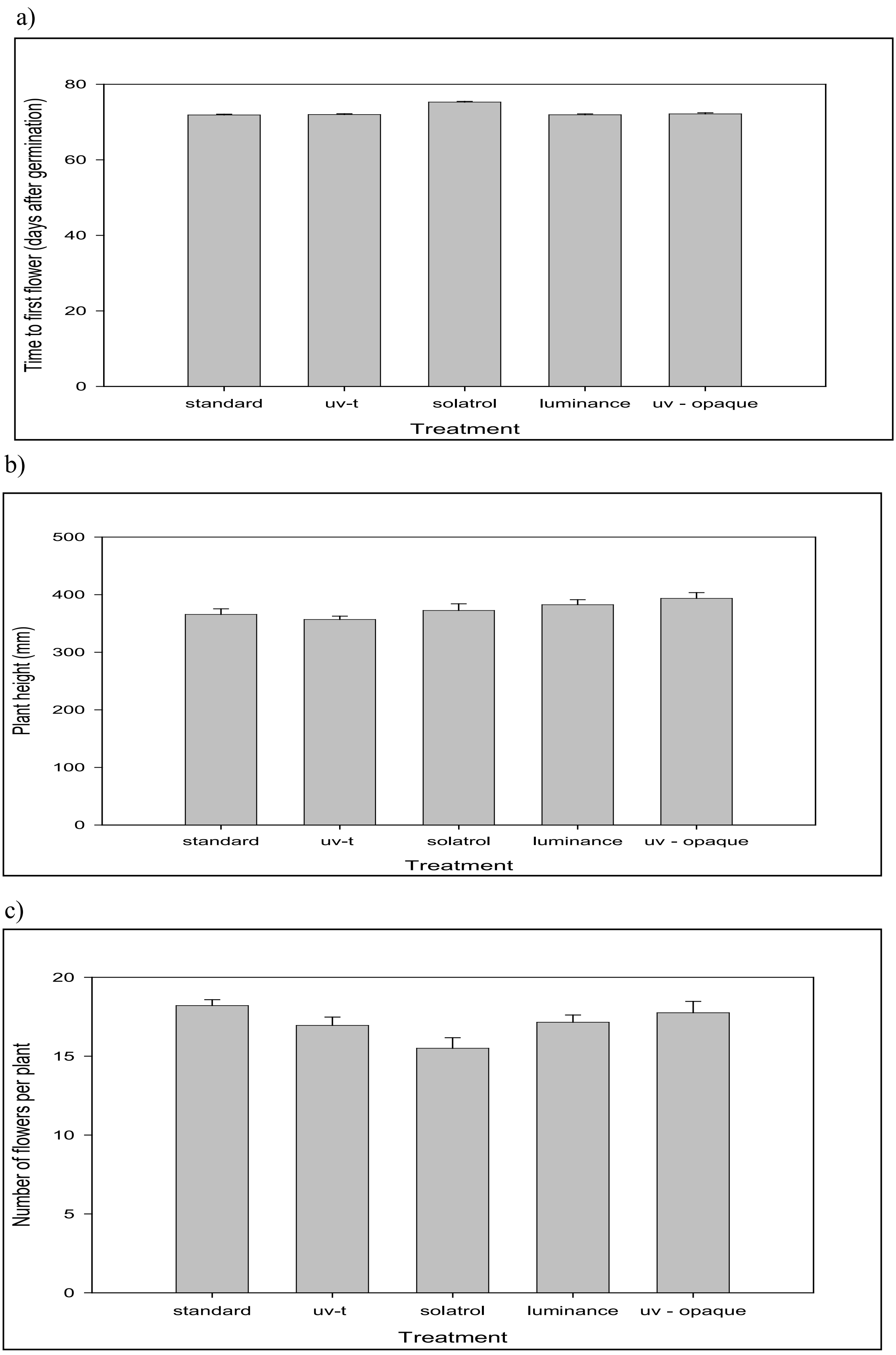
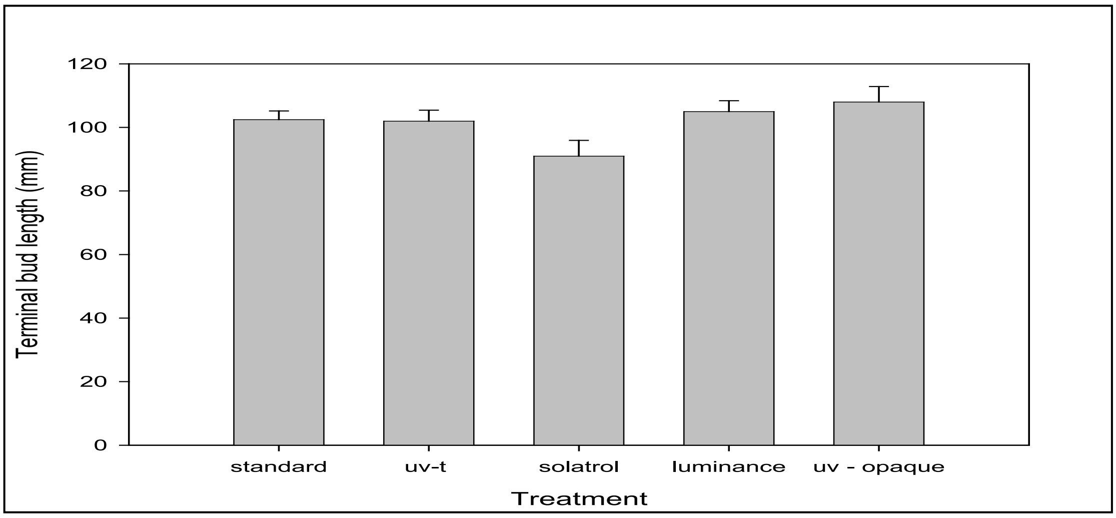


Figure 2. Effect of treatment on (a) time to flowering (b) plant height and (c) number of flowers per plant in Antirrhinums. Each value is the mean ± S.E. of 20 replicates.

a)



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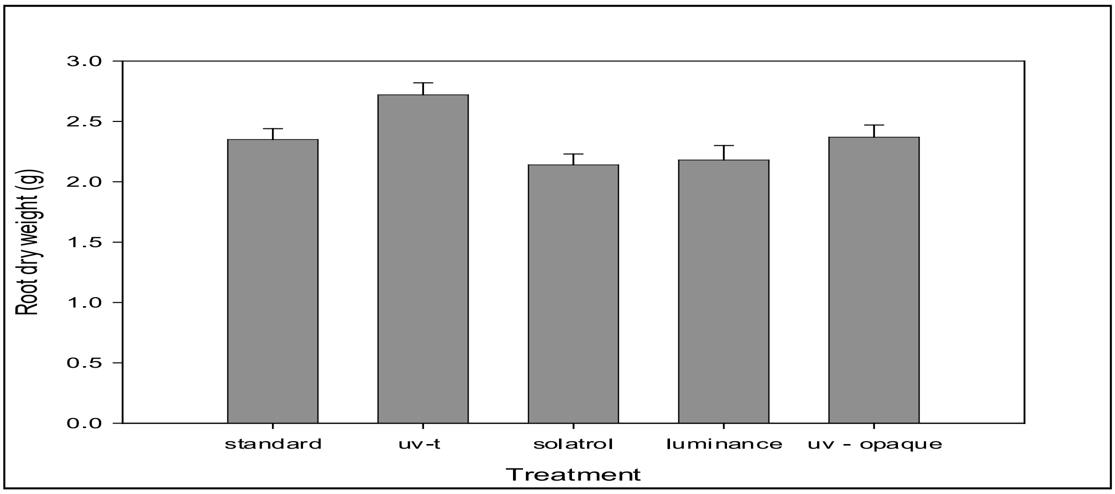


Figure 3. Effect of treatment (a) terminal bud length and (b) root dry weight in Antirrhinums. Each value is the mean ± S.E. of 20 replicates.

PANSIES

BLUE VARIETY

There were no significant effects of treatments on shoot fresh weight (data not presented). However, both root fresh and dry weights were significantly increased in Standard and were reduced under Luminance (Figs. 1.a & 1.b). Under UV-transparent flower diameter was significantly reduced when compared to Luminance and UV-opaque only (Fig. 1.c). UV-transparent also increased the thickness of the oldest leaf at the time of harvest when compared to Luminance and UV-opaque (Fig. 2.a). The thickness of the newest leaf was significantly increased in Standard when compared to both Solatrol and Luminance (Fig. 2.b). Finally, Solatrol significantly extended time to flowering when compared to UV-opaque only (data not presented). Flower colour was more intense under the UV-transparent filter than other treatments. This effect was not quantified but can be clearly seen in Figure 3.

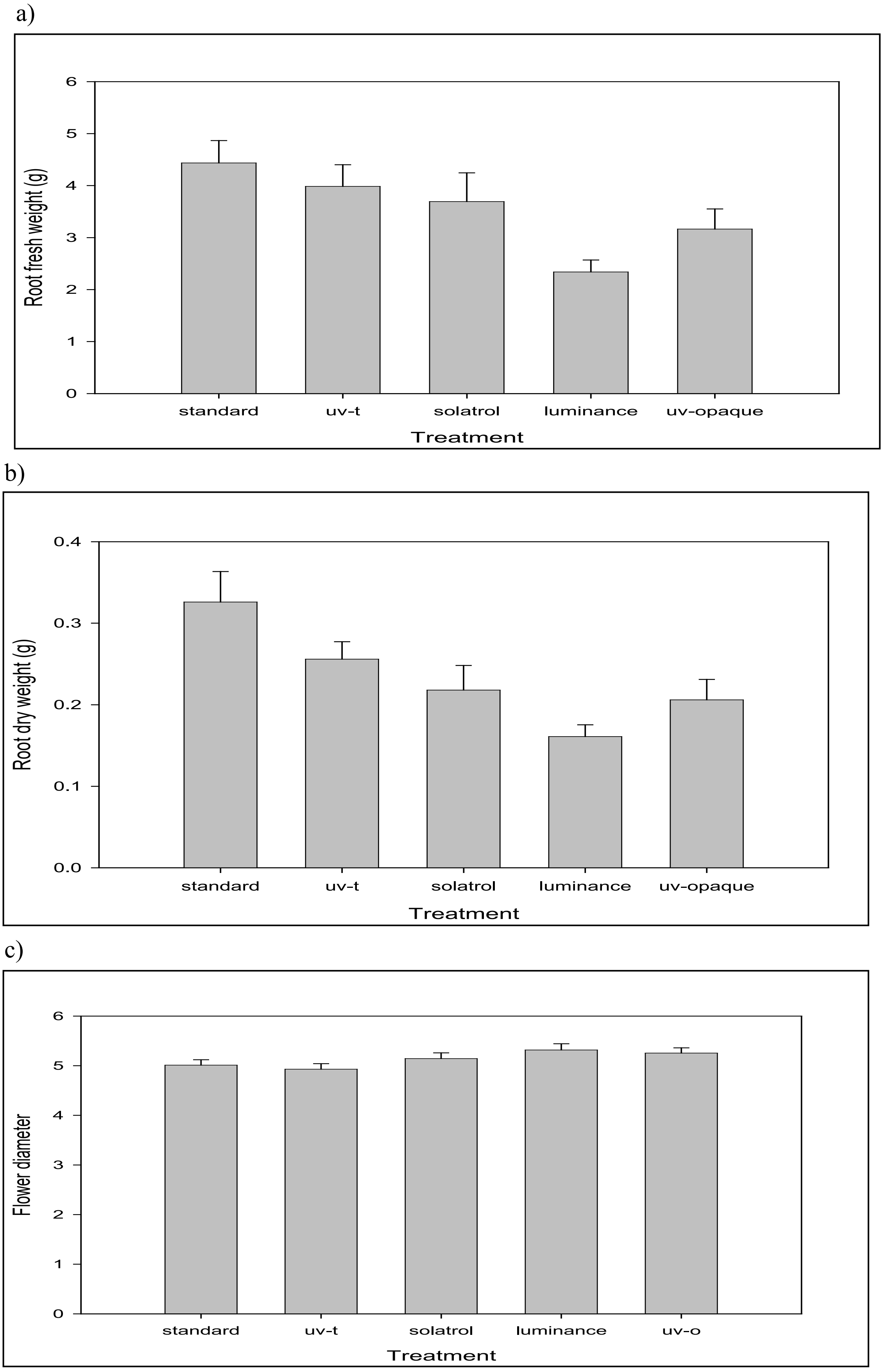
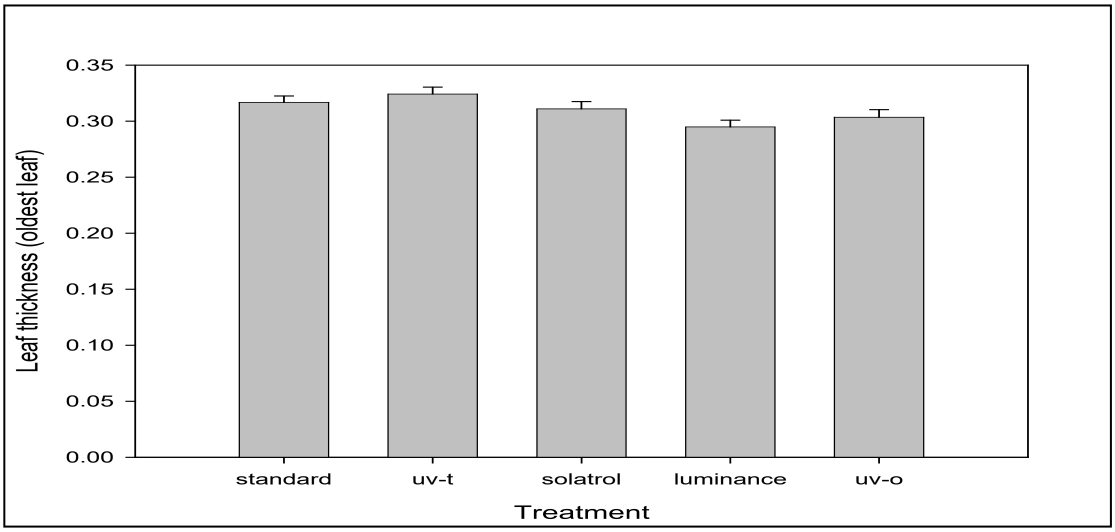


Figure 1. Effect of treatment on (a) root fresh weight (b) root dry weight and (c) flower diameter of blue Pansy. Each value is the mean ± S.E. of 20 replicates.

a)



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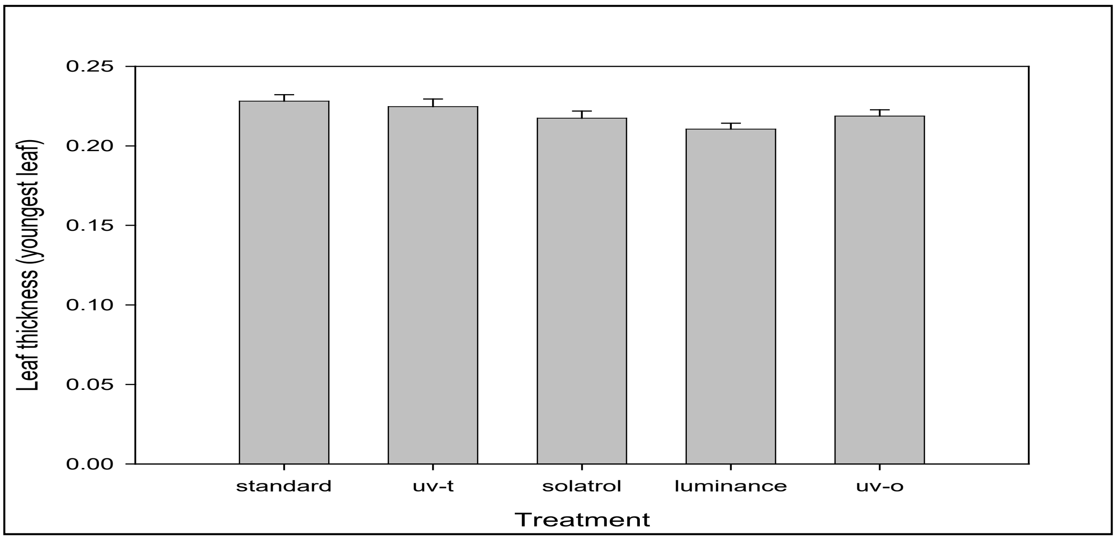


Figure 2. Effect of treatment on (a) leaf thickness–oldest leaf and (b) leaf thickness – youngest leaf of blue Pansy. Each value is the mean ± S.E. of 20 replicates.

Figure 3. Flower colour change was observed in Blue Pansy.

RED VARIETY

There were no significant effects of treatments on shoot fresh weight (data not presented). However, both root fresh and dry weights were significantly higher in both Standard and UV-transparent and were reduced under Luminance (Figs. 4.a & 4.b). In red Pansies there were no significant effects of treatments on flower diameter (Fig. 4.c). With regards to leaf thickness, Standard significantly increased the thickness of the oldest leaf when compared to UV-opaque, while Solatrol significantly reduced the thickness of the newest leaf relative to Luminance, UV-opaque, Standard and UV-transparent (Figs. 5.a. & 5.b). UV-opaque significantly reduced the time to harvest compared to Standard, UV-transparent and Solatrol only, while Solatrol significantly delayed harvest relative to Luminance and UV-opaque (Fig. 5.c).

As with the blue variety, flower colour was more intense under the UV-transparent filter than other treatments. The effect can be clearly seen in Figure 6.

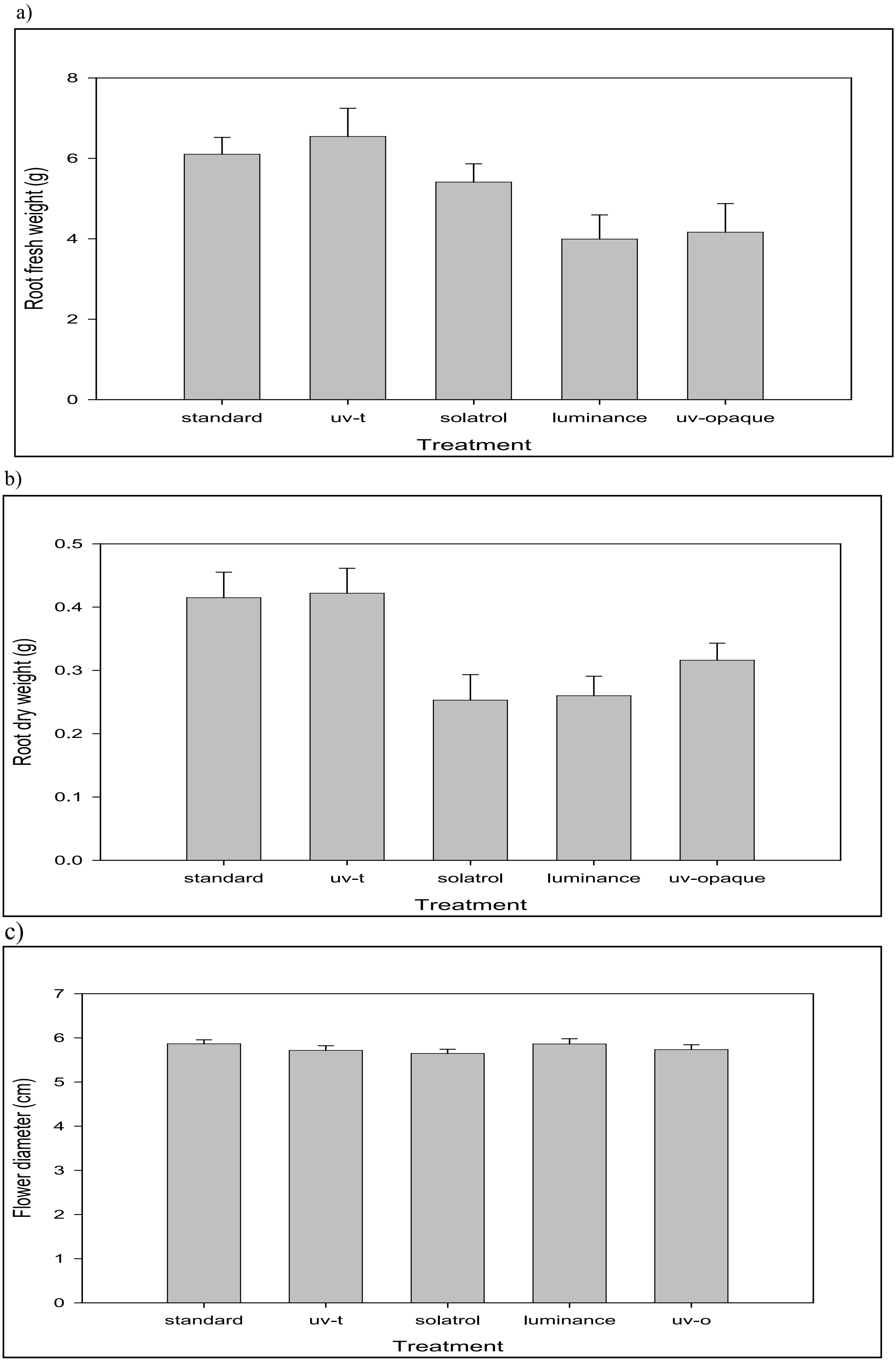
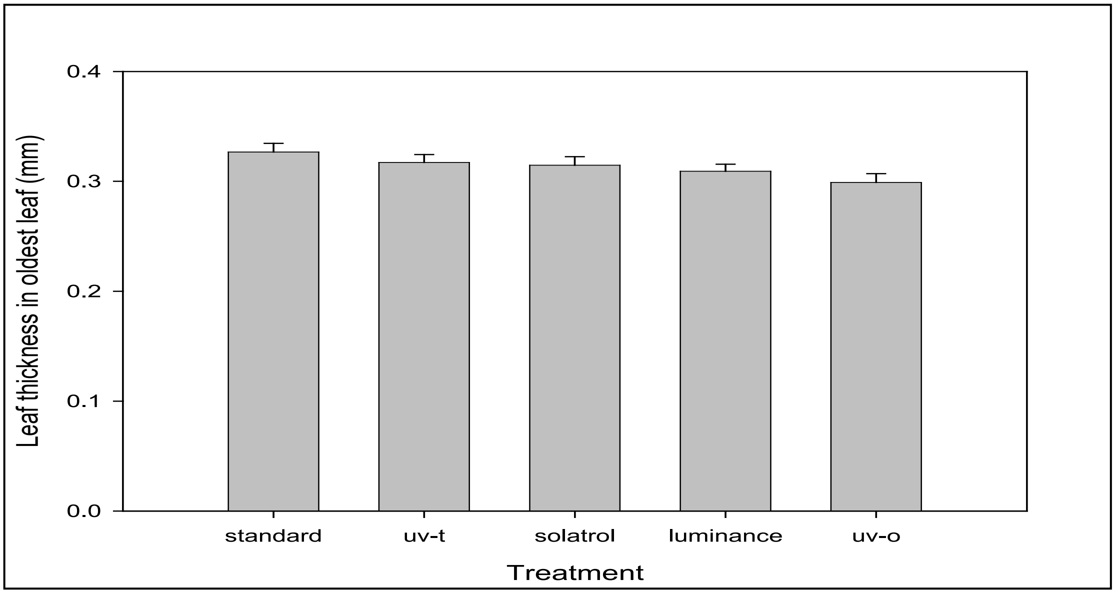


Figure 4. Effect of treatment on (a) root fresh weight and (b) root dry weight and (c) flower diameter of red Pansy. Each value is the mean ± S.E. of 20 replicates.

a)



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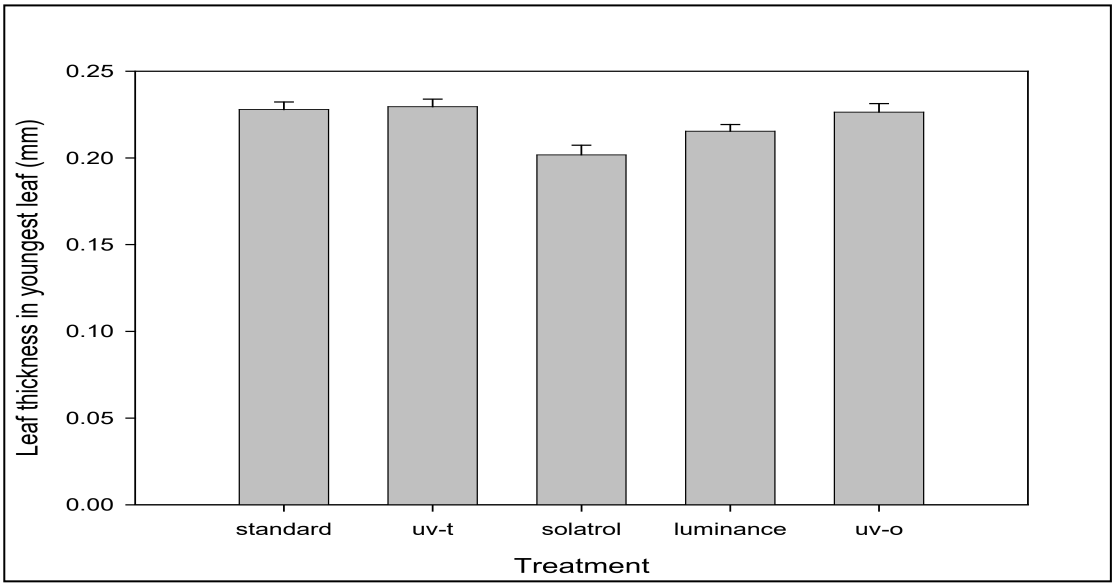


Figure 5. Effect of treatment on (a) leaf thickness – oldest leaf and (b) leaf thickness – youngest leaf of red Pansy. Each value is the mean ± S.E. of 20 replicates.

Figure 6. Flower colour change was observed in red Pansy.

YELLOW VARIETY

There were no significant effects of treatments on shoot fresh weight (data not presented). However, both root fresh and dry weights were increased in both Standard and UV-transparent and were significantly reduced in UV-opaque (Figs. 7.a & 7.b). UV-opaque also increased flower diameter but only compared to Solatrol (Fig. 7.c). UV-opaque significantly reduced the time to harvest when compared to Standard, Solatrol, and Luminance, although there was no effect relative to UV-transparent (Fig. 7.c).

No differences in flower colour were observed between treatments with this variety.

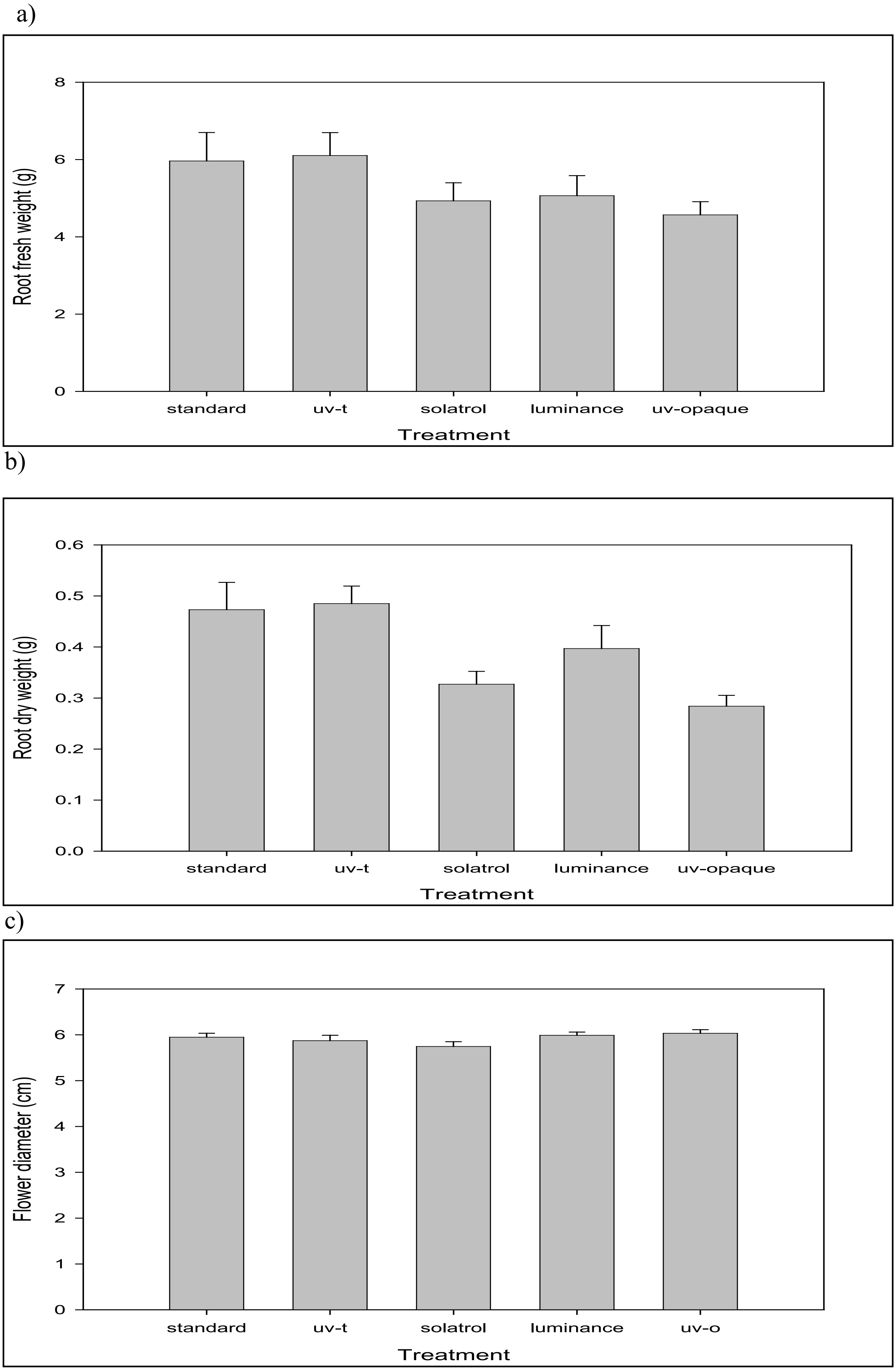


Figure 7. Effect of treatment on (a) root fresh weight (b) root dry weight and (c) flower diameter in yellow Pansy. Each value is the mean ± S.E. of 20 replicates.

Discussion

The first years study revealed more intense flower colouration in blue and red Pansy grown under the UV-transparent filter. This suggests that certain cultivars of Pansy may respond to high levels of UV light by increasing the synthesis of anthocyanonins, which as well as been integral in flower colouration, are utilised by plants for protection against the damaging effects of high UV.

The filters also altered bedding plant development and morphology. For instance, in both Antirrhinums and blue Pansy, the time to harvest was increased by several days in those plants grown under the Solatrol filter. In red and yellow Pansy time to harvest was reduced under the UV-opaque filter. The filters also modified flower development. In Antirrhinums, the total number of flowers per plant was increased under the Standard filter and reduced under Solatrol. The diameter of the flower was increased in blue Pansy under the Luminance filter and in yellow Pansy under the UV-opaque filter. Results from the first seasons study are encouraging in so far as we have observed a number of potentially beneficial effects for growers in switching to production under spectral filters. However, the effects of the individual filters are far from uniform across species and so further investigation in the coming season is warranted.

PART 5. CUT FLOWERS

Introduction

The consumption of cut flowers in the UK remains very buoyant with total imports in 2003 valued at over £550 million and production from UK growers approaching £60 million. This could well be an under estimate as the statistics rely heavily on information from The Netherlands which may under-estimate direct imports into the UK from Kenya, Colombia and Ecuador etc. Primarily the supermarkets have driven growth in the cut flower market with growth year on year approaching 15-20%. It is now thought that growth is slowing but is still above 10%. For the purpose of analysis the UK cut flower industry can be divided into two main sectors: the greenhouse protected crops sector and the outdoor / polythene tunnel sector.

According to ministry (DEFRA) returns the greenhouse-protected sector covers an area of 150 Ha. Bulbous crops cover a total area of 4,500 Ha. The majority of the remaining area is either used for the production of Chrysanthemums or Alstroemeria. Rose production in the UK has declined to zero because of overseas competition, mainly from Kenya. The production of Carnations and pinks has declined over the last ten years but now appears to have stabilized.

The area of Matthiola being grown under glass has steadily increased over the last five years and is now approaching 25 Ha (Simon Crawford - personal assessment). The expansion of this crop is now limited by the lack of adequate greenhouses and lower cost alternatives are being sought by growers in an attempt to further expand production without raising the price of the product to the consumer.

Outdoor production in the UK is reported to cover a total area of 5,500 Ha. The greater part of this area, 4,500 Ha, is devoted to bulbous crops. Daffodil bulb production, outdoor Tulips and Gladioli are still major crops in the eastern counties of the country. The production of seed raised crops is highly fragmented, but a few large growers producing Sunflowers, Chinese Asters, Larkspur and Carthamus are responsible for at least 150 Ha of production.

Current outdoor cut flower producers and other farmers and growers seeking to diversify their business into cut flowers are searching for lower cost alternatives to glasshouses and traditional polythene tunnels. A facility that would allow growers to protect their crops from the weather and give a basic level of environmental control in order to ensure ‘on-time’ delivery of crops is essential when serving UK supermarkets with high volume products.

The development of low cost Spanish tunnel systems for strawberries and other soft fruit crops has presented growers with a real option in the search for an adequate solution to their need for a basic level of lower cost environmental control and assured harvesting. Therefore improvement of these systems through technical developments in more sophisticated tunnel designs and plastic coverings for the structures is essential for the progress of these systems in the UK.

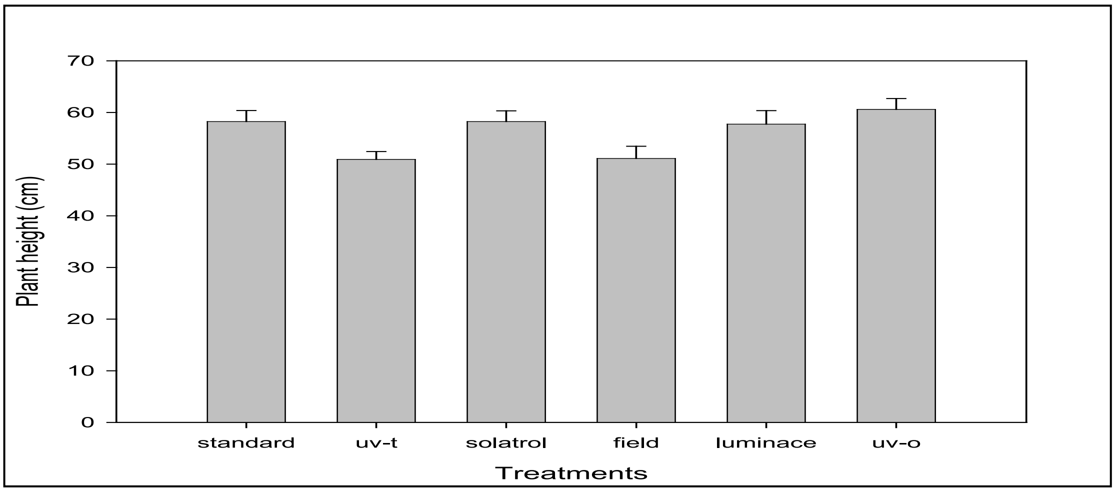
Work at Stockbridge Technology Centre over the last twelve months has reconfirmed the usefulness of low cost tunnel systems and the necessity for further research work into the advantages of spectral filters used in this type of cropping system.

RESULTS - STOCKS

PINK STOCKS

Plant height was significantly reduced by UV-transparent compared to all other plastics, but not compared with the field. Plants grown under UV-opaque were also significantly taller than those grown in the field (Fig. 1.a). There were no significant differences in stem diameter between the five plastics, but stem diameter at the base of the plant was significantly greater in plants grown in the field than in any other treatments (Fig. 1.b)

a)



b)

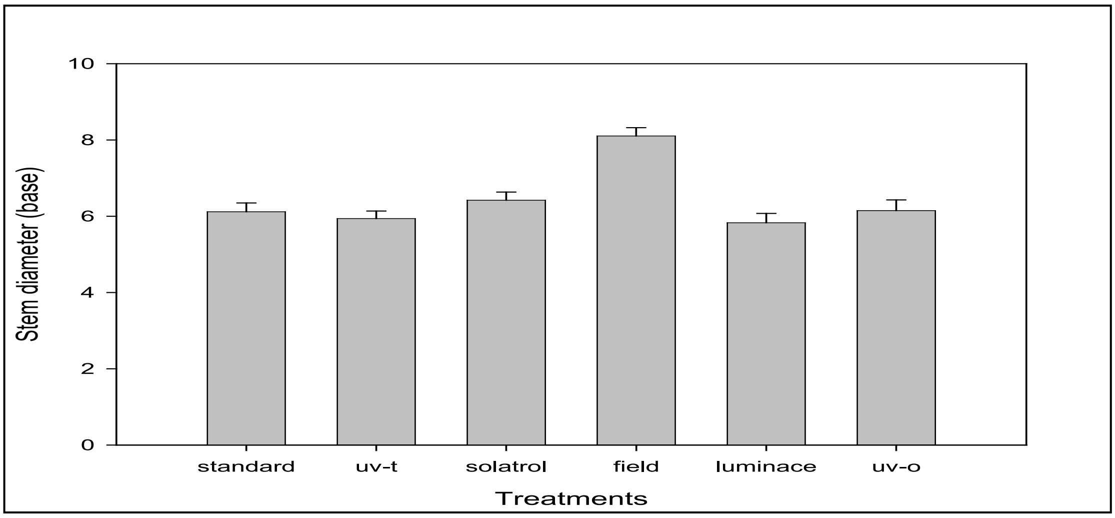
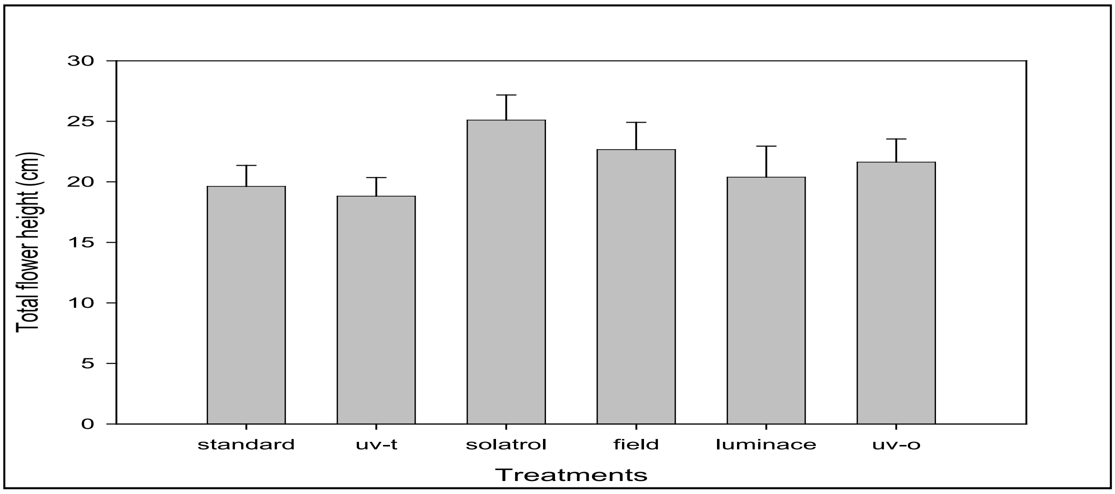


Figure 1. Effect of treatment on (a) plant height (b) stem diameter at the base of the plant in ink Stocks. Each value is the mean ± S.E. of 20 replicates.

The length of the terminal inflorescence (the marketable "flower spike") was significantly greater under Solatrol compared to Luminance, the Standard and UV-transparent film (Fig. 2.a). There were no other significant effects of treatments on inflorescence length (Fig. 2.a). Plants grown under Solatrol produced significantly more inflorescences than plant grown under all other plastics, but not when compared to Field grown plants (Fig. 2.b). There were no other significant effects of treatments on inflorescence production (Fig. 2.b).

a)



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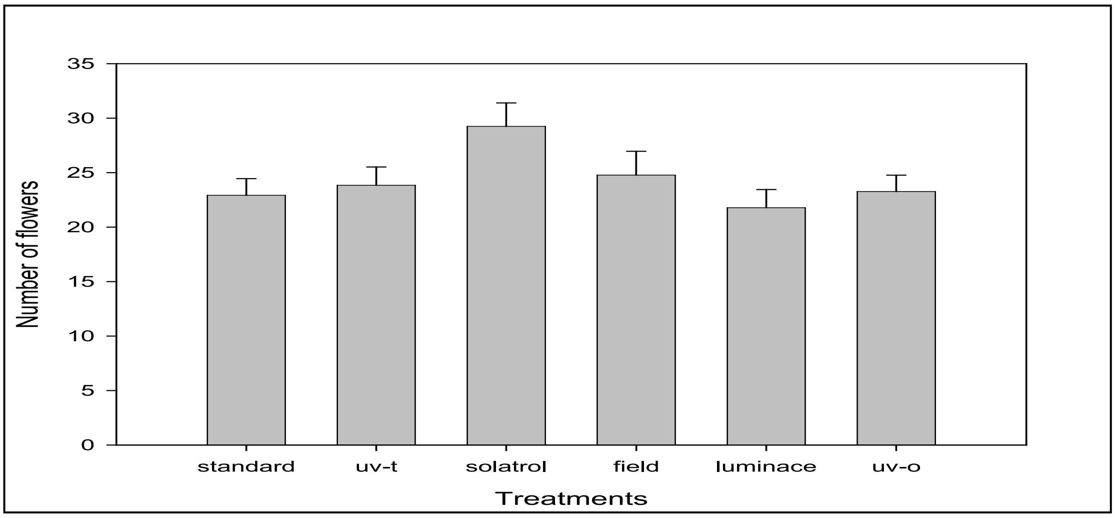


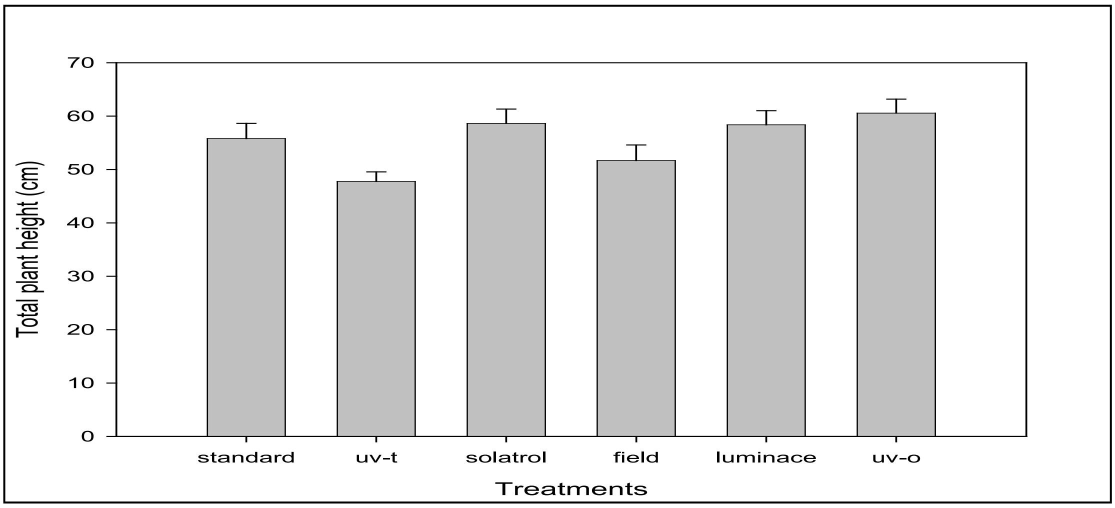
Figure 2. Effect of treatments on (a) total inflorescence length and (b) number of inflorescences in Pink stocks. Each value is the mean ± S.E. of 20 replicates.

WHITE STOCKS

Plant height was significantly reduced by UV-transparent compared to all other plastics, but not compared with the field (Fig 3.a). There were no other significant differences in plant height. There was a highly significant increase in stem diameter at the base of plants grown in the field compared to all remaining treatments (Fig. 3.b). Amongst the plastics, basal stem diameter was significantly lower under UV-transparent compared to Solatrol and UV-opaque, but not Luminance (Fig. 3.b).

There were also no significant effects of treatments on the number or length of terminal inflorescences (data not presented).

a)



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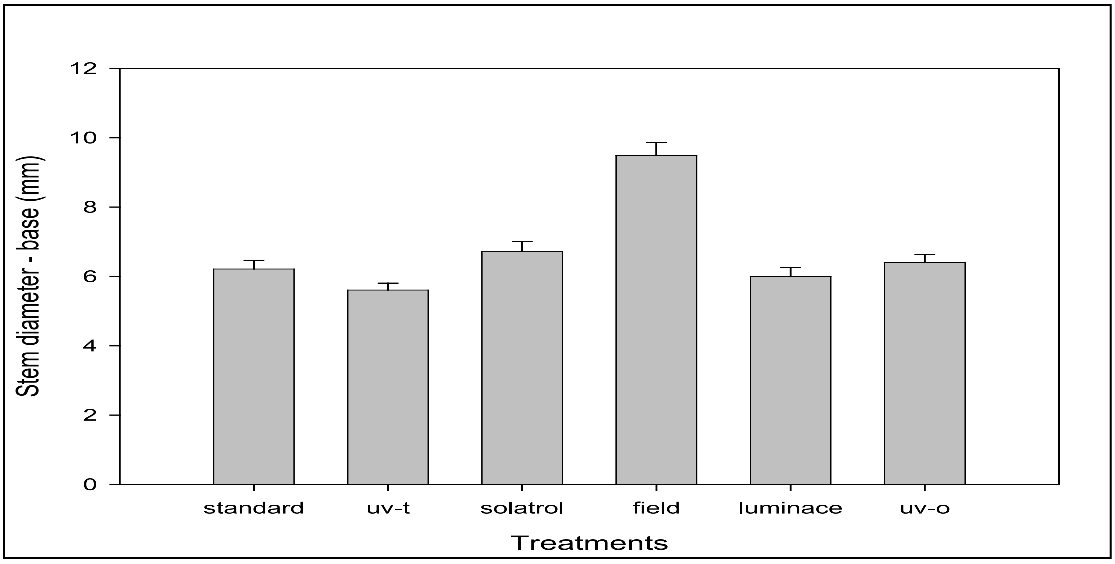
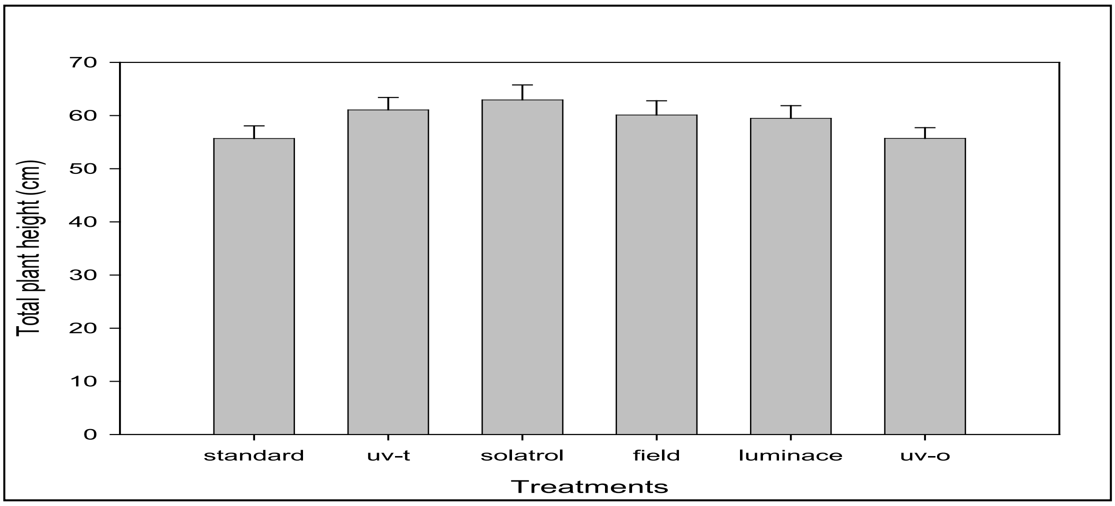


Figure 3. Effect of treatment on (a) plant height and (b) basal stem diameter in White stocks. Each value is the mean ± S.E. of 20 replicates.

PURPLE STOCKS

The only significant effect on plant height was an increase under Solatrol compared with UV-opaque and Standard (Fig. 4.a). There was a significant increase in basal stem diameter in plants grown in the Field when compared to all other treatments (Fig. 4.b). Amongst the plastics, the only significant difference was a reduction under UV-opaque film compared to UV-transparent (Fig. 4.b). The length of the terminal inflorescence (the marketable “flower spike”) was significantly greater under Solatrol compared to Luminance, Standard and UV-transparent film (Fig. 5.a). In addition, inflorescences were significantly shorter under Standard film than in plants produced under UV-transparent, Solatrol, or field (Fig. 5.a). The number of inflorescences was significantly greater in Solatrol than UV-opaque or Standard (Fig. 5.b). UV-opaque produced the least number of flowers and this was a significant reduction compared to UV-transparent and Solatrol (Fig. 5.b).

a)



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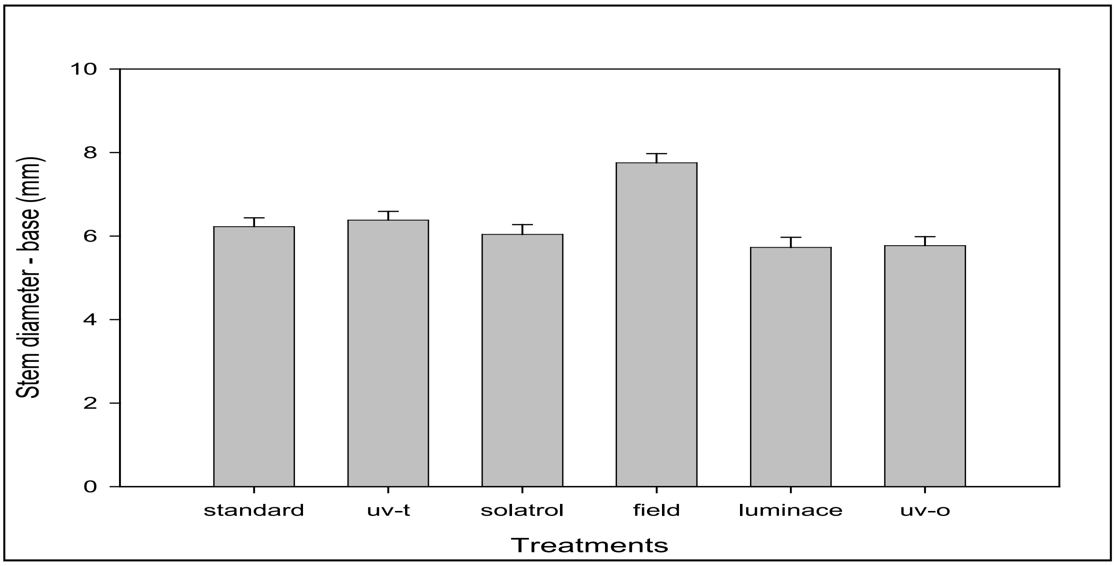


Figure 4. Effect of treatment on (a) plant height and (b) basal stem diameter in purple Stocks. Each value is the mean ± S.E. of 20 replicates.

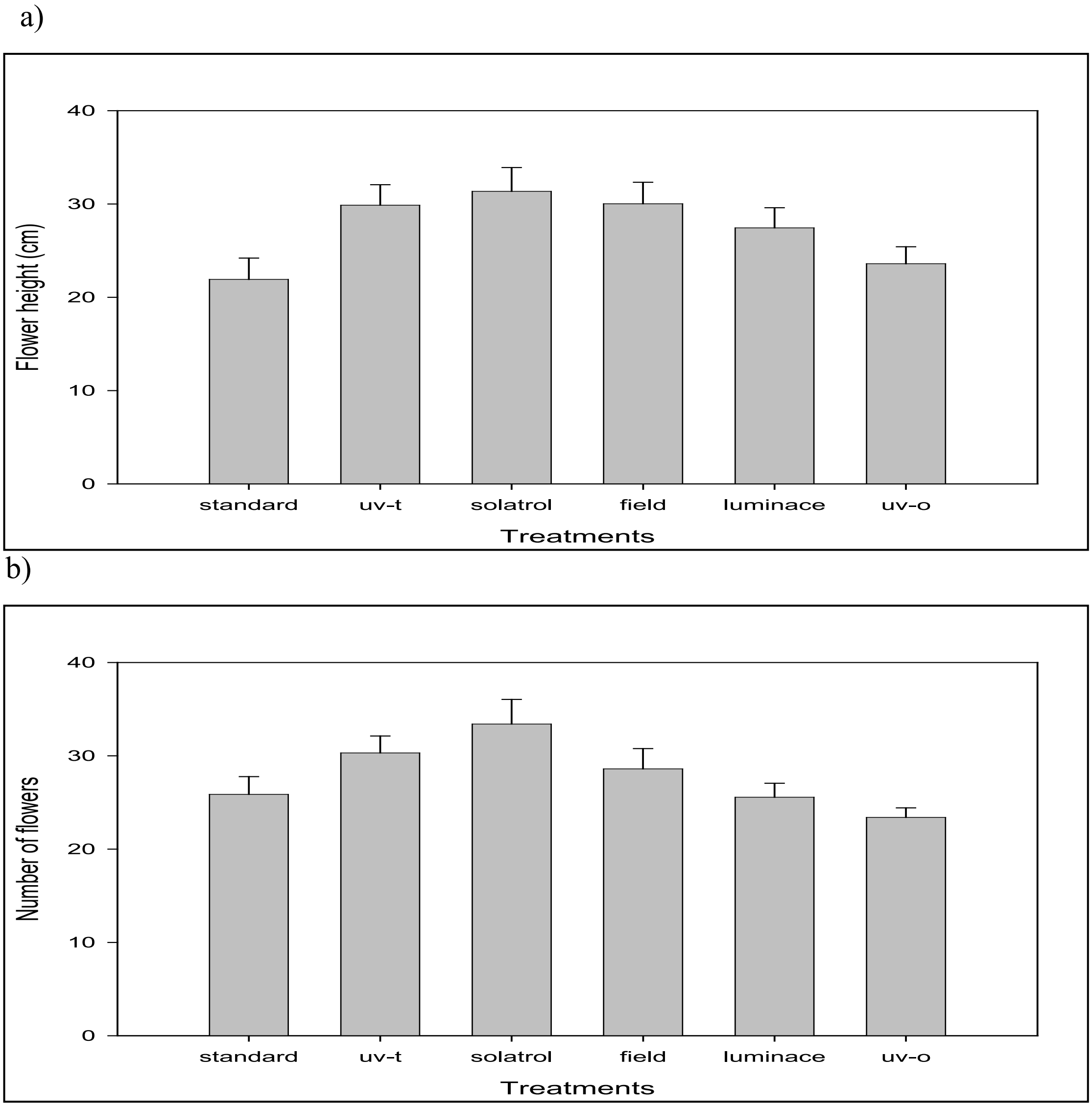
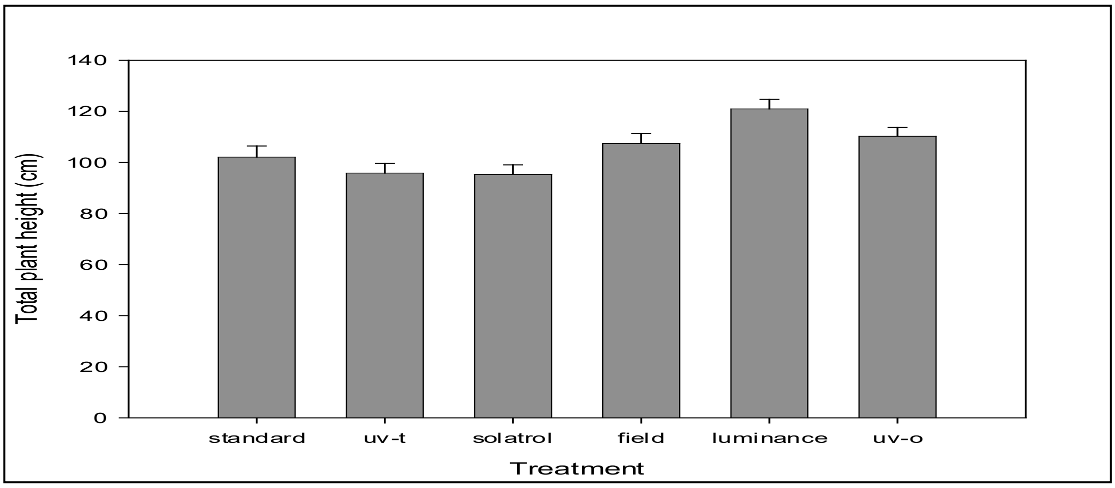


Figure 5. Effect of treatment on (a) total inflorescence length and (b) number of inflorescences in Purple stocks. Each value is the mean ± S.E. of 20 replicates.

RESULTS – LARKSPUR

Plant height was significantly increased in Luminance when compared to all other treatments (Fig. 6.a). Basal stem diameter in Field grown plants was significantly greater than under UV-opaque, Standard and UV-transparent, but not Luminance or Solatrol (Fig. 6.b). Amongst the plastics, basal stem diameter was significantly less under UV-transparent than Solatrol or Luminance (Fig. 6.b). There were no significant effects of treatments on the number of basal branches ("breaks": data not presented) but the number of secondary, or ancillary, branches was greater in Field-grown plants than under any of the plastics (Fig. 7.a). Field-grown plants produced significantly more inflorescences than any of the plastics (Fig. 7.b). Of the plastics, plants grown under UV-transparent produced significantly fewer inflorescences than other treatments, excluding the Standard film (Fig. 7.b) There were no other effects of treatment in the number of flowers per inflorescence (data not presented). The only significant treatment effect on the length of the inflorescences was a significant reduction under UV-transparent compared with Standard (Fig. 7.c).

a)



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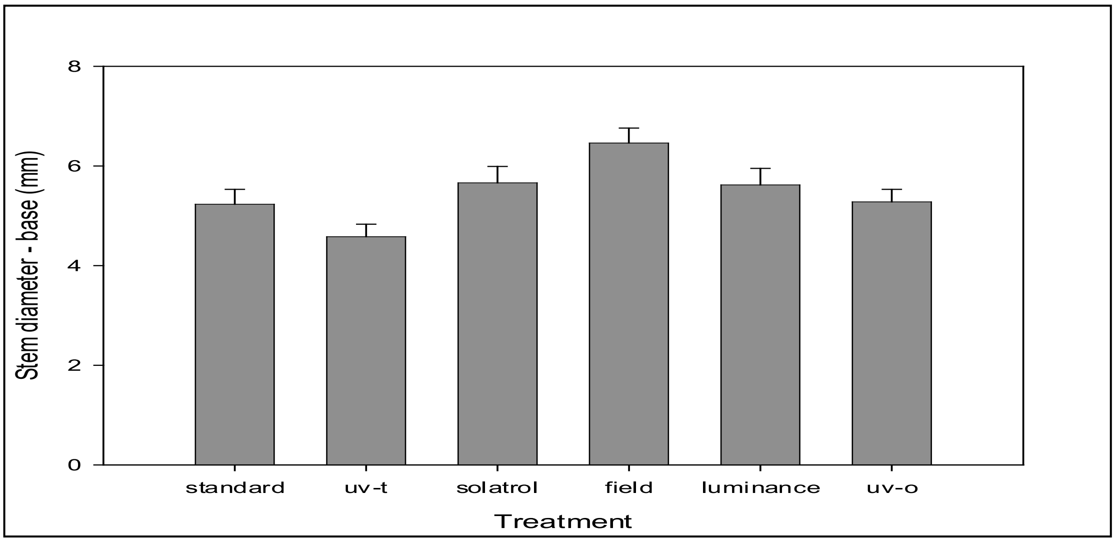


Figure 6. Effect of treatment on (a) plant height and (b) basal stem diameter in Larkspur. Each value is the mean ± S.E. of 20 replicates.

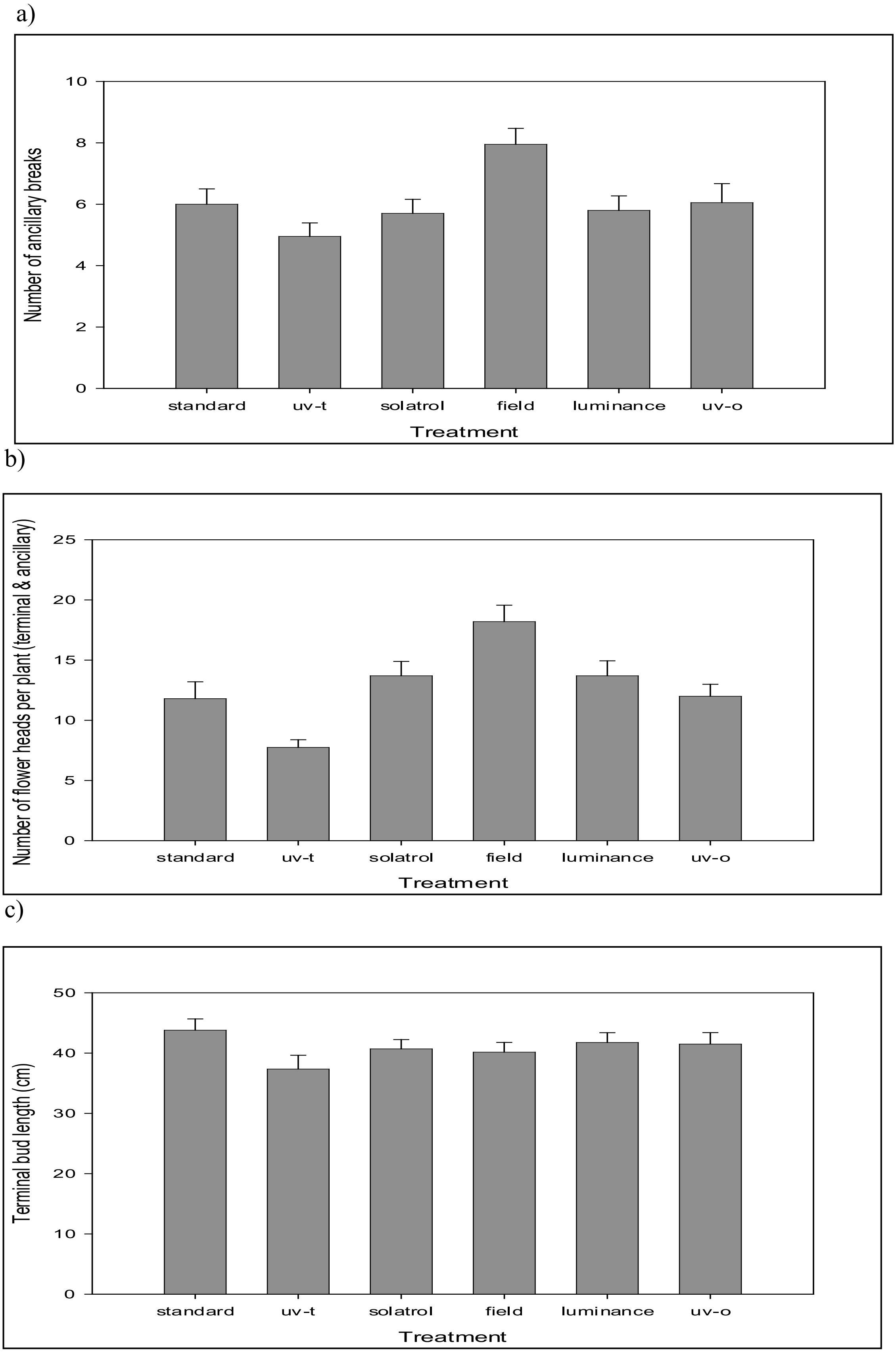


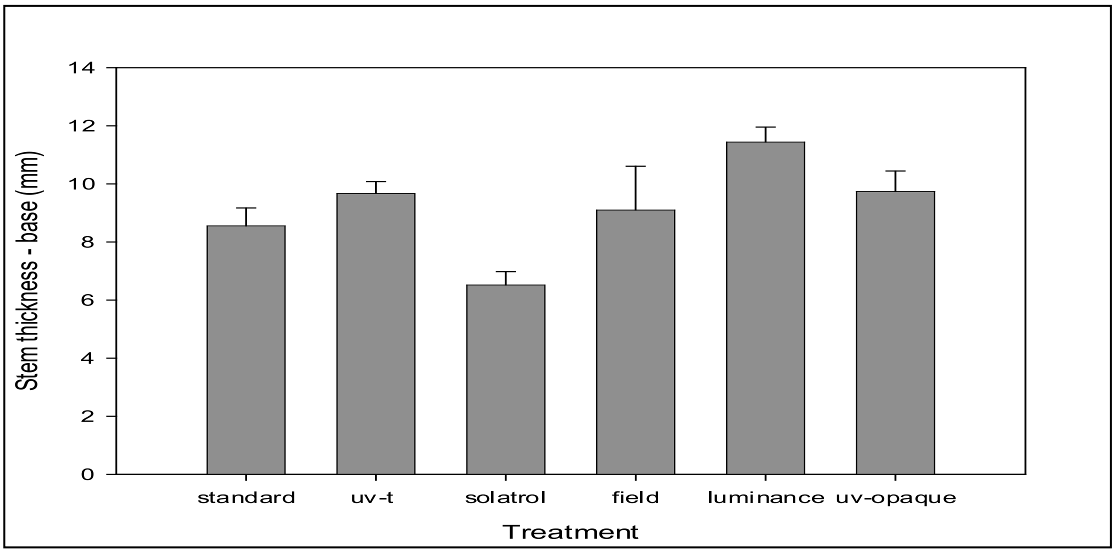
Figure 7. Effect of treatment on (a) number of ancillary breaks, (b) total number of inflorescences per plant and (c) terminal inflorescence length in Larkspur. Each value is the mean ± S.E. of 20 replicates.

RESULTS – DELPHINIUM

GUINIVERE

There were no significant effects of treatments on plant height (data not presented). Basal stem thickness was significant greater in Luminance compared to Standard, UV-transparent and Solatrol, but not compared to UV-opaque or Field-grown plants (Fig. 8.a). The length of the terminal bud, or primary inflorescence, was significantly greater in plants grown under Solatrol than in the Field or under Luminance or UV-transparent, and was also significantly less under UV-transparent than under UV-opaque or Standard film (Fig. 8.b). The only significant treatment effect on the number of flowers in the primary inflorescence was an increase in plants grown under Solatrol relative to UV-opaque and UV-transparent (Fig. 9.a). The number of secondary inflorescences was significantly greater UV-opaque than under the remaining five treatments (Fig. 8.b).

a)



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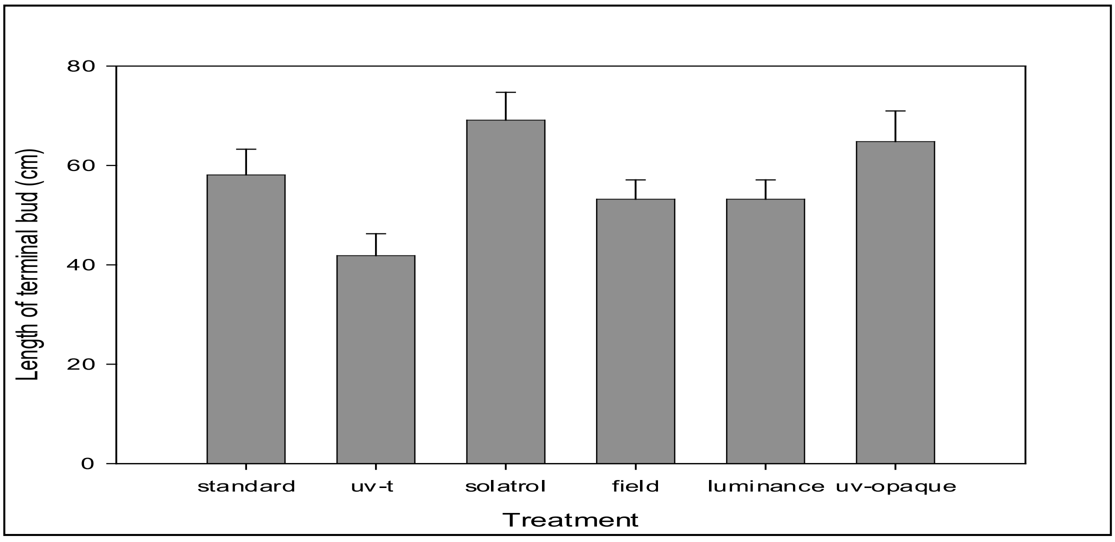


Figure 8. Effect of treatment on (a) stem thickness – base and (b) the length of the primary inflorescence in *Delphinium* cv "Guineviere". Each value is the mean + S.E. of 10 replicates.

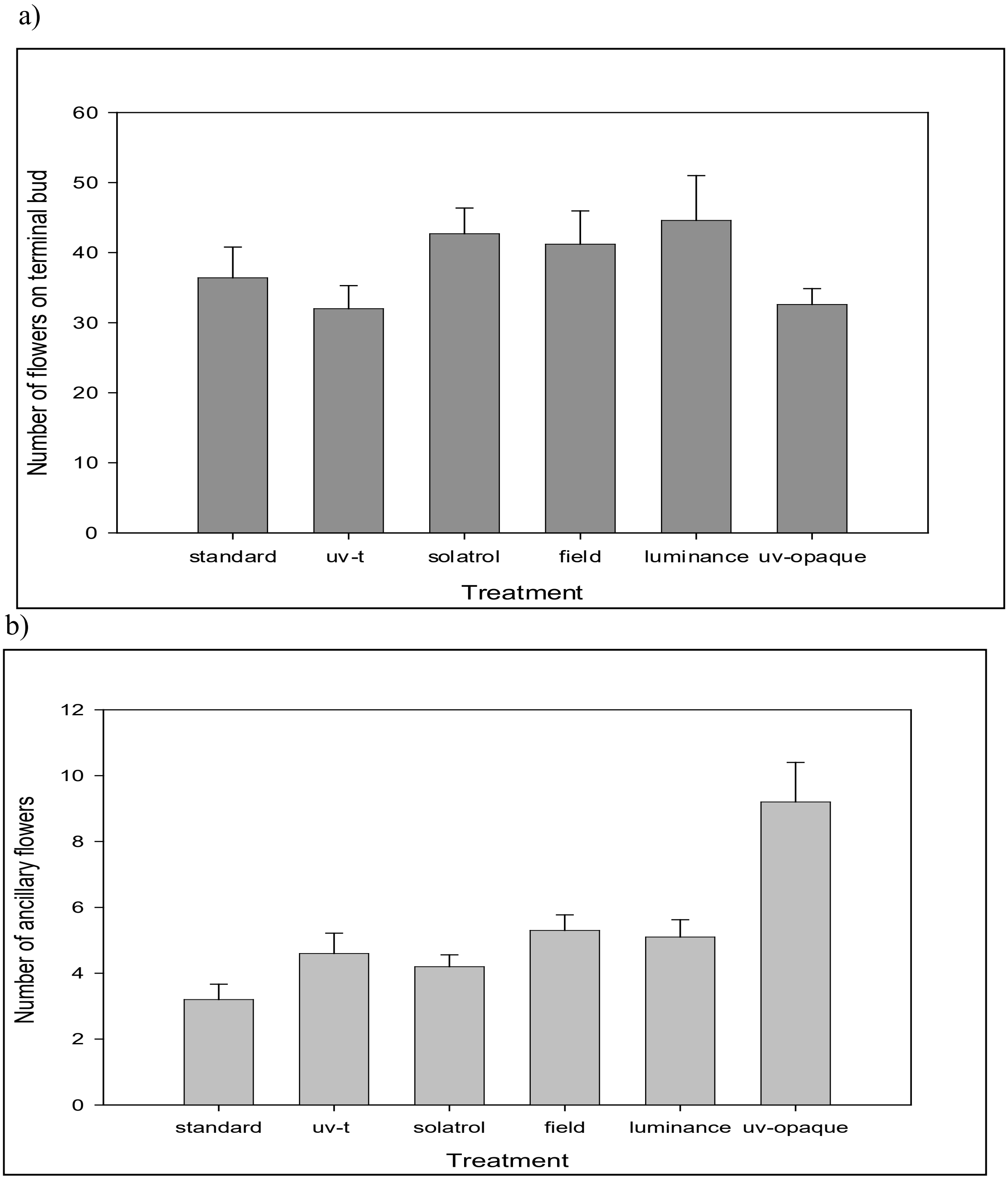


Figure 9. Effect of treatment on (a) number of flowers on the primary inflorescence (b) number of secondary flowers in *Delphinium* cv "Guineviere". Each value is the mean ± S.E. of 10 replicates.

BLUEBIRD

There were no significant effects of treatments on plant height (data not presented). Basal stem thickness was significantly increased in Luminance than in all other plastics, but not compared to the field (Fig. 10.a). There were no significant effects of treatments on number of secondary inflorescences (data not presented). The length of the primary inflorescence was reduced in plants grown under Standard film than under any other treatment (Fig. 10.b). The only significant treatment effect on the number of flowers in the primary inflorescence was an increase in plants grown under Luminance relative to Standard and Solatrol (Fig. 10.c). Ancillary flower numbers were significantly reduced in Solatrol when compared to Field and Luminance only (data not presented).

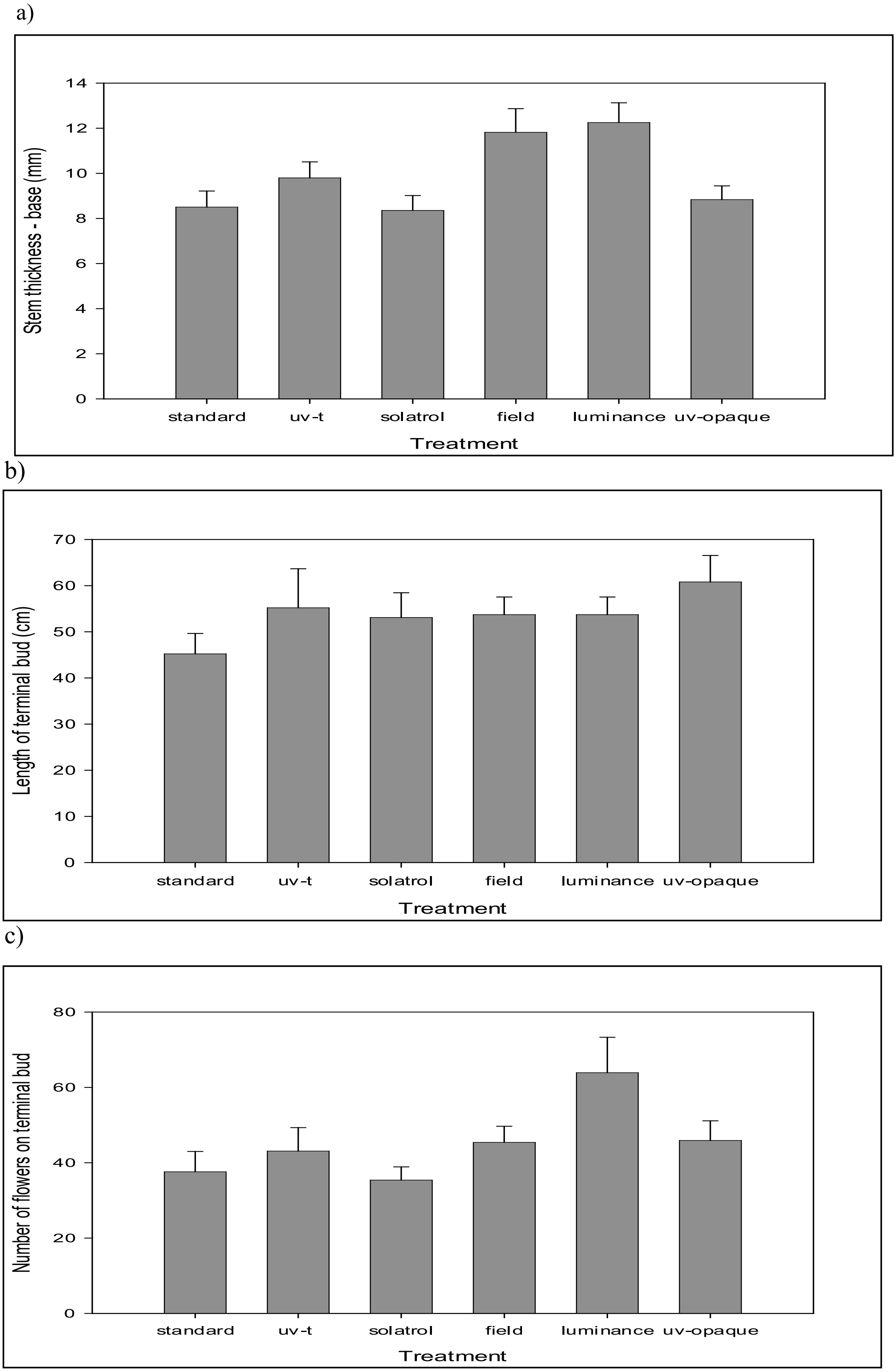
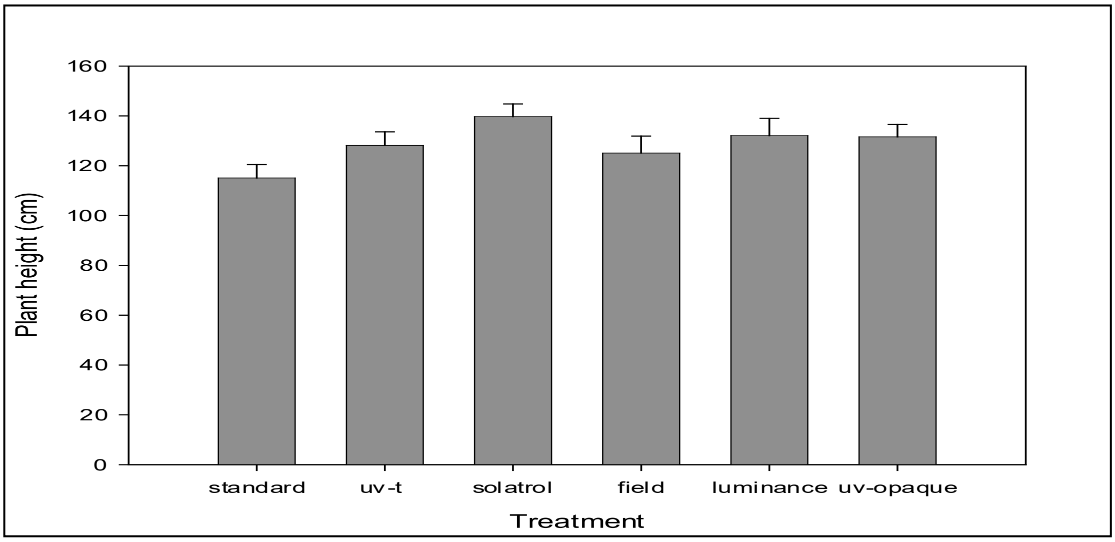


Figure 10. Effect of treatment on (a) stem thickness - base (b) length of the primary inflorescence and (c) number of flowers on the primary inflorescence in *Delphinium* cv "Bluebird". Each value is the mean ± S.E. of 10 replicates.

SUMMER SKIES

The only significant treatment effect on plant height was an increase in Solatrol relative to Standard film (Fig. 11.a). Basal stem thickness was significantly increased in UV-opaque relative to Standard film, UV-transparent and Solatrol films, but not compared Luminance or the field (Fig 11.b). There were no significant effects of treatments on number of secondary inflorescences (data not presented). The length of the primary inflorescence was significantly less in plants grown under Standard film than under Solatrol, Luminance, or in the field (Fig 12.a). There were no significant treatment effects on the number of flowers in the primary inflorescence (data not presented). There was, however, a significant increase in the number of ancillary flowers in field when compared to the Luminance, Standard and Solatrol films, although there was no significant effect relative to UV-opaque and UV-transparent (Fig. 12.b).

a)



b)

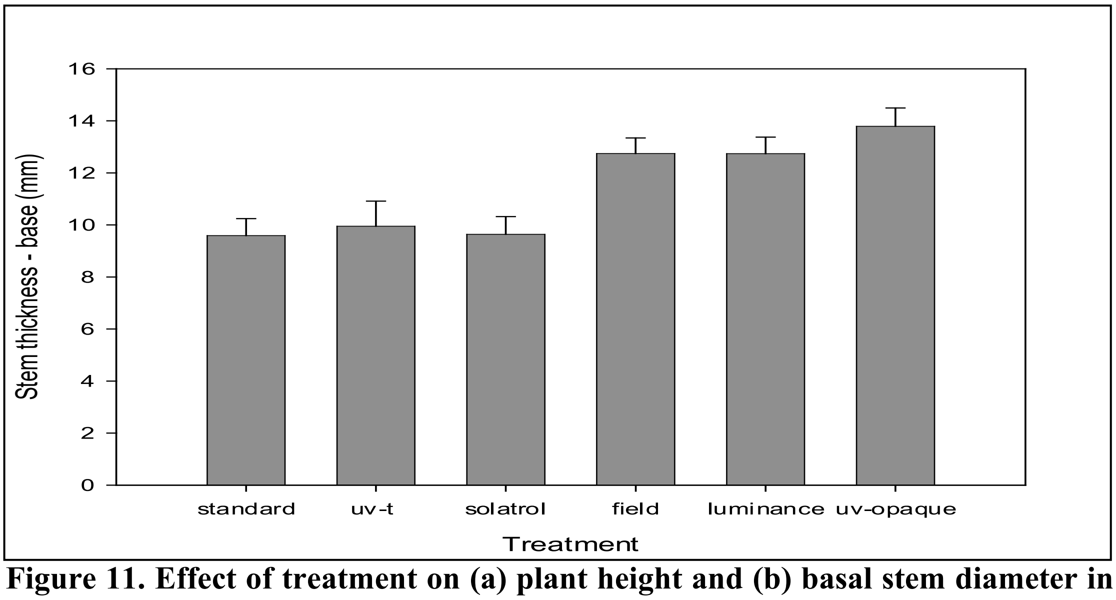
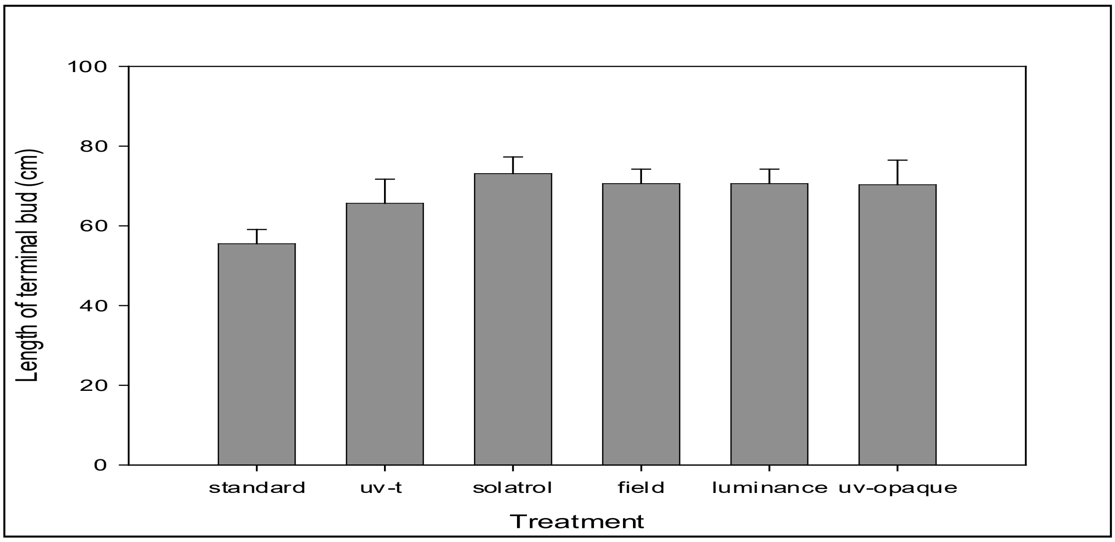


Figure 11. Effect of treatment on (a) plant height and (b) basal stem diameter in *Delphinium* cv "Summer Skies". Each value is the mean ± S.E. of 10 replicates.

a)



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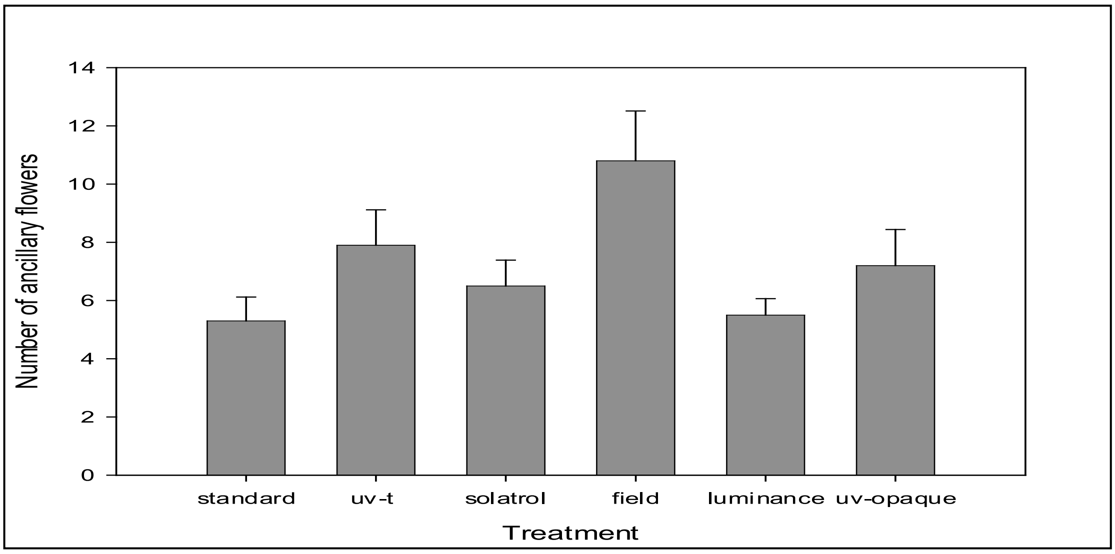


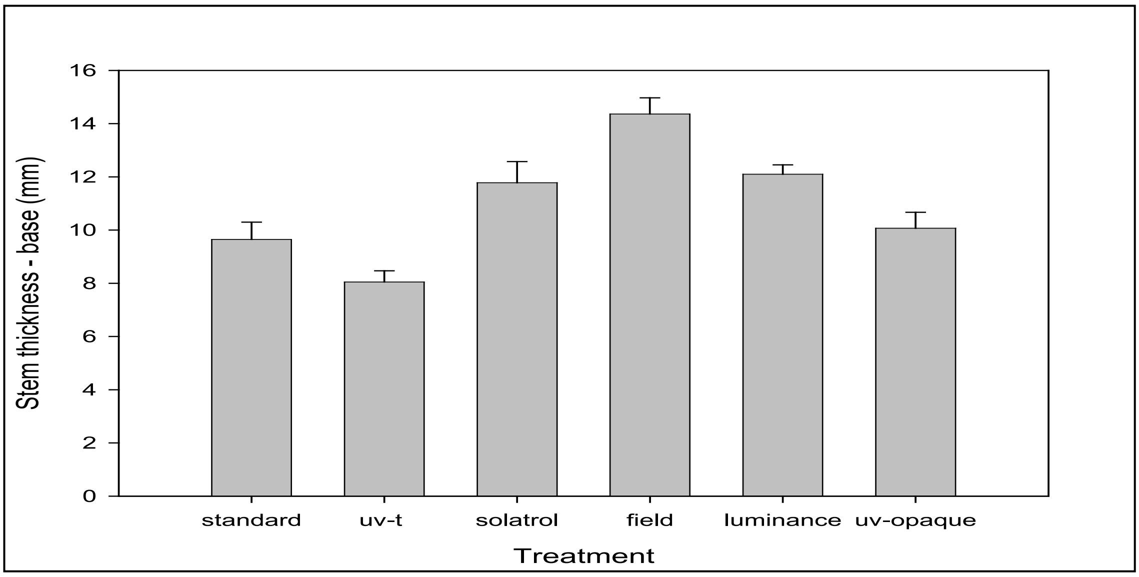
Figure 12. Effect of treatment on (a) the length of the primary inflorescence (b) number of ancillary flower in *Delphinium* cv "Summer Skies". Each value is the mean ± S.E. of 10 replicates.

GALAHAD

There were no significant effects of treatments on plant height (data not shown). Basal stem thickness was significantly greater in Field-grown plants than in any other treatment (Fig. 13.a.). Amongst the plastics, UV-transparent significant reduced stem thickness compared to all but the standard film (Fig. 13.a). There were no significant effects of treatments on the number of secondary inflorescences (data not presented). The length of the primary inflorescence was significantly greater in field-grown plants than in plants grown under Standard film, UV-transparent and Solatrol films, but not compared to Luminance or UV-opaque (Fig. 13.b). Amongst the plastics, primary inflorescences were significantly shorter in plants grown under UV-transparent compared Luminance and UV-opaque, but not Standard and Solatrol (Fig. 13.b). The only significant treatment effect on the number of flowers in the primary inflorescence was a significant reduction in UV-opaque when compared to field and

Luminance (Fig. 14.a). Ancillary flower numbers were significantly increased in field when compared to all films (Fig. 14.b).

a)



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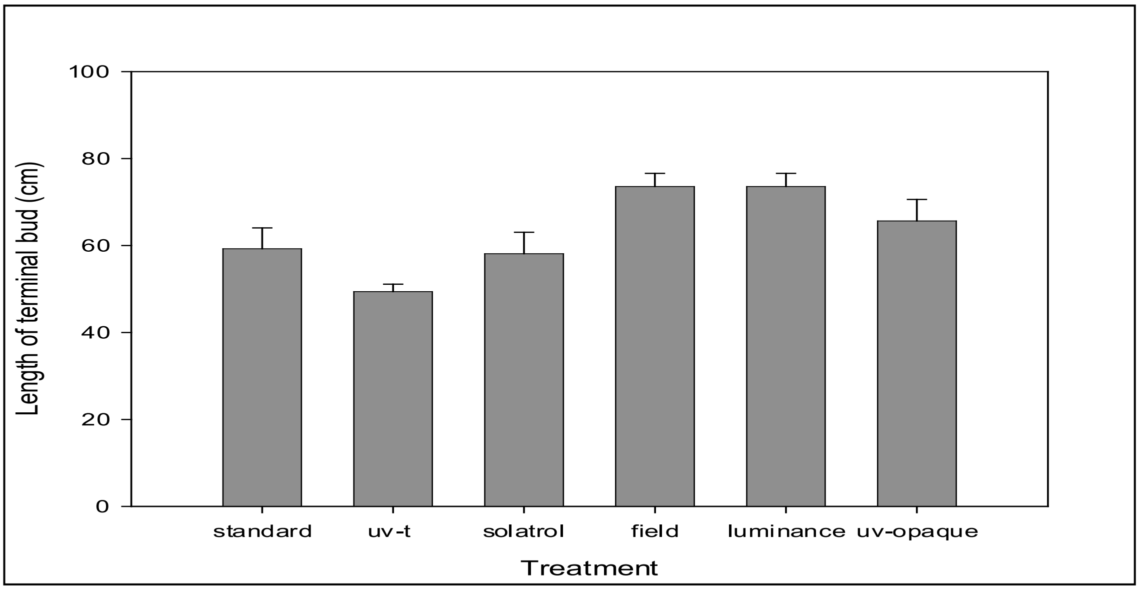
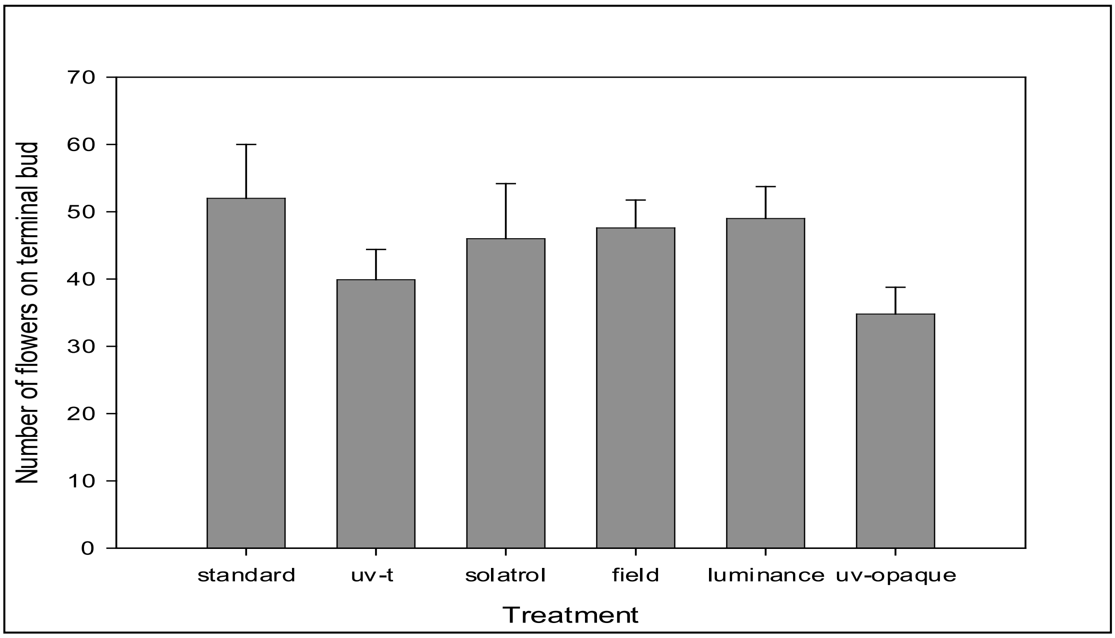


Figure 13. Effect of treatment on (a) basal stem diameter and (b) the length of the primary inflorescence in *Delphinium* cv "Galahad". Each value is the mean ± S.E. of 10 replicates.

a)



b)

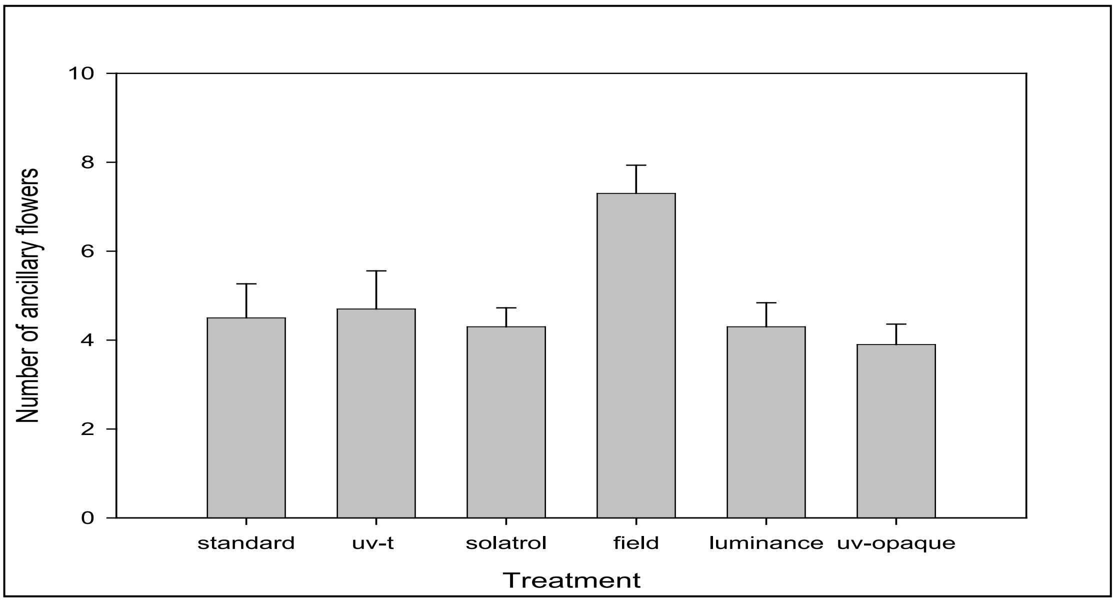


Figure 14. Effect of treatment on (a) number of flowers in the primary inflorescence and (b) number of ancillary flowers in *Delphinium* cv "Galahad". Each value is the mean ± S.E. of 10 replicates.

KING ARTHUR

There were no significant effects of treatments on plant height (data not presented). Stem thickness at the base was significantly reduced under UV-transparent when compared to field grown plants and under the Solatrol and Standard films (Fig. 15.a). Standard exhibited the greatest increase in stem thickness and this was a significant increase compared to UV-transparent, Luminance and UV-opaque filters (Fig. 15.a). The UV-transparent filter reduced the length of the terminal inflorescence compared to Solatrol only (data not presented). The number of flowers on the terminal inflorescence was reduced in UV-transparent compared to field grown plants and Solatrol and UV-opaque films (Fig. 15.b). The Solatrol film increased the incidence of ancillary flowers, however, this did not represent a statistically significant increase when compared to the other treatments (Fig. 16). Under Luminance, ancillary flower numbers were significantly reduced relative to Standard and field grown plants only (Fig. 16.).

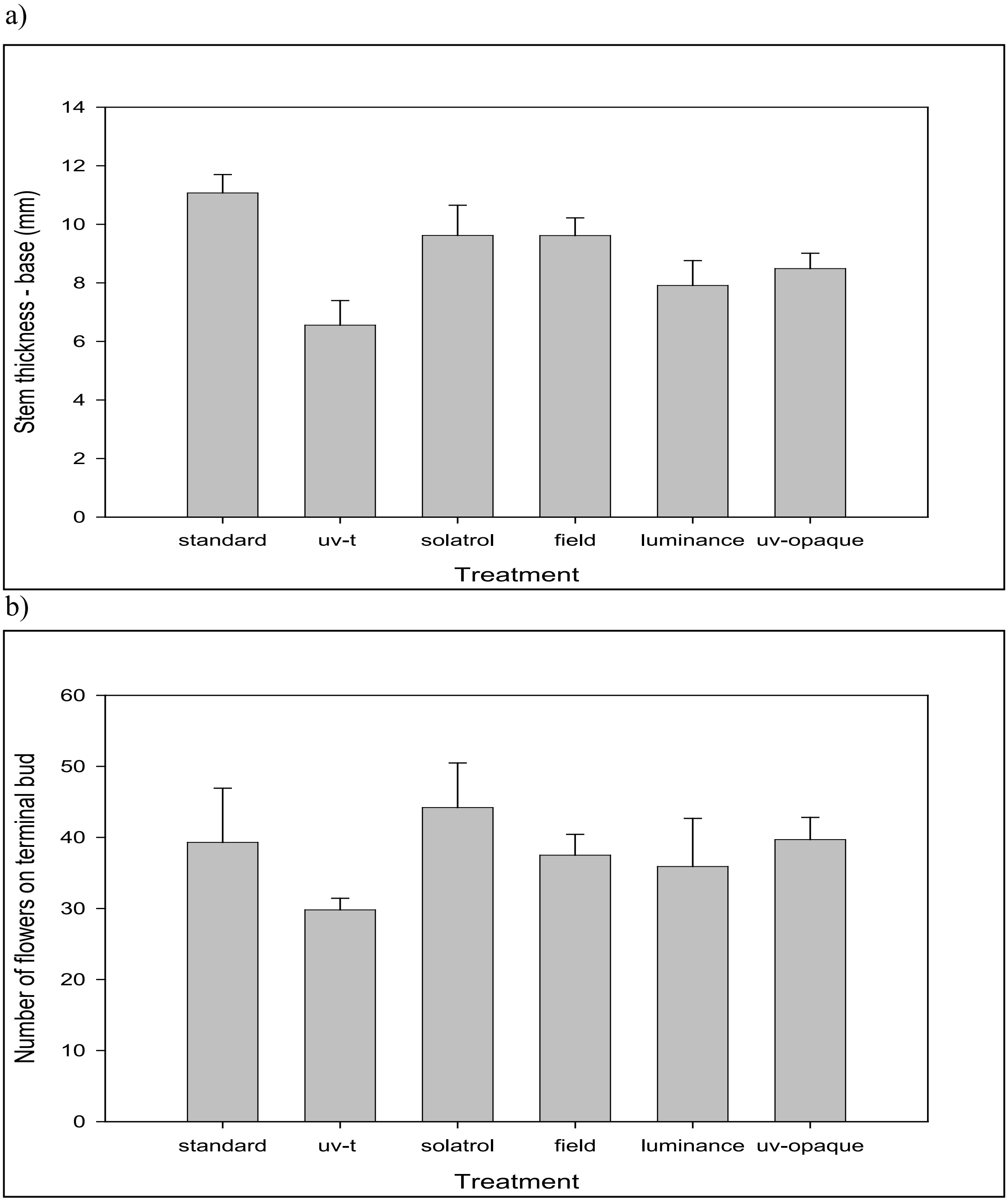


Figure 15. Effect of treatments on (a) stem thickness – base and (b) number of flowers on the terminal inflorescence in *Delphinium* cv "King Arthur". Each value is the mean ± S.E. of 10 replicates.

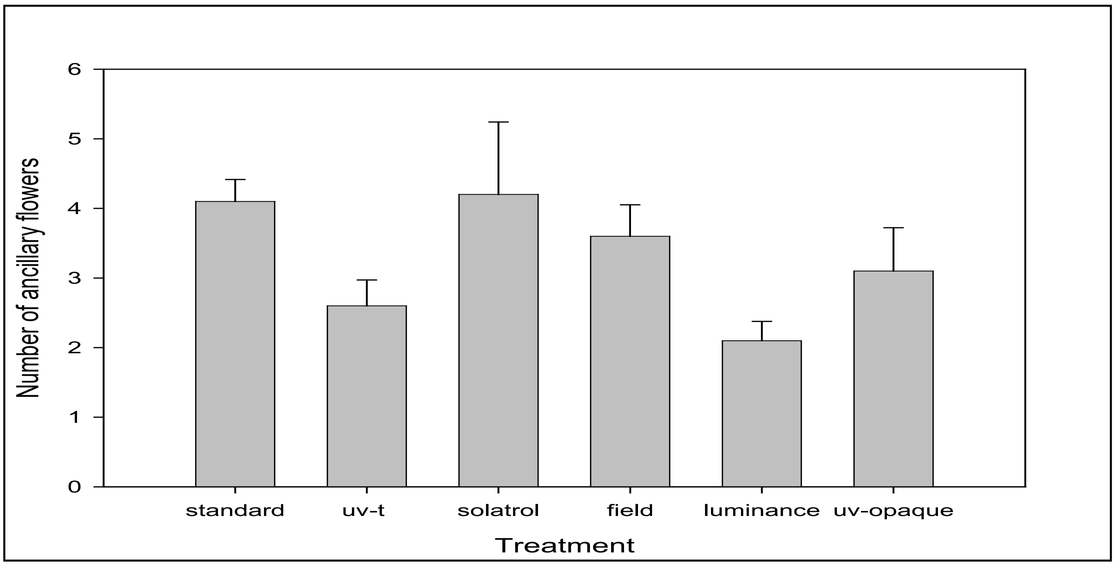


Figure 16. Effect of treatment on the number of ancillary flowers in *Delphinium* cv "King Arthur". Each value is the mean ± S.E. of 10 replicates.

RESULTS – BLACK KNIGHT

Plant height was reduced in Field grown plants when compared to all films (Fig. 17.a). Solatrol significantly increased plant height when compared to field plants and UV-opaque and UV-transparent films only (Fig. 17.a). Stem thickness at the base increased in Luminance compared to UV-opaque, Standard, Solatrol and Field treatments (Fig. 17.b).

The length of the terminal inflorescence was increased under the UV-opaque film when compared to Field, Standard and Luminance treatments (Fig. 17.c). The number of flowers on the terminal bud was significantly reduced under UV-opaque when compared to Standard only (data not presented). The number of ancillary breaks was higher in Field grown plants when compared to the Solatrol film only (Fig. 18) and there were no significant effects of treatments on the number of ancillary flowers (data not presented).

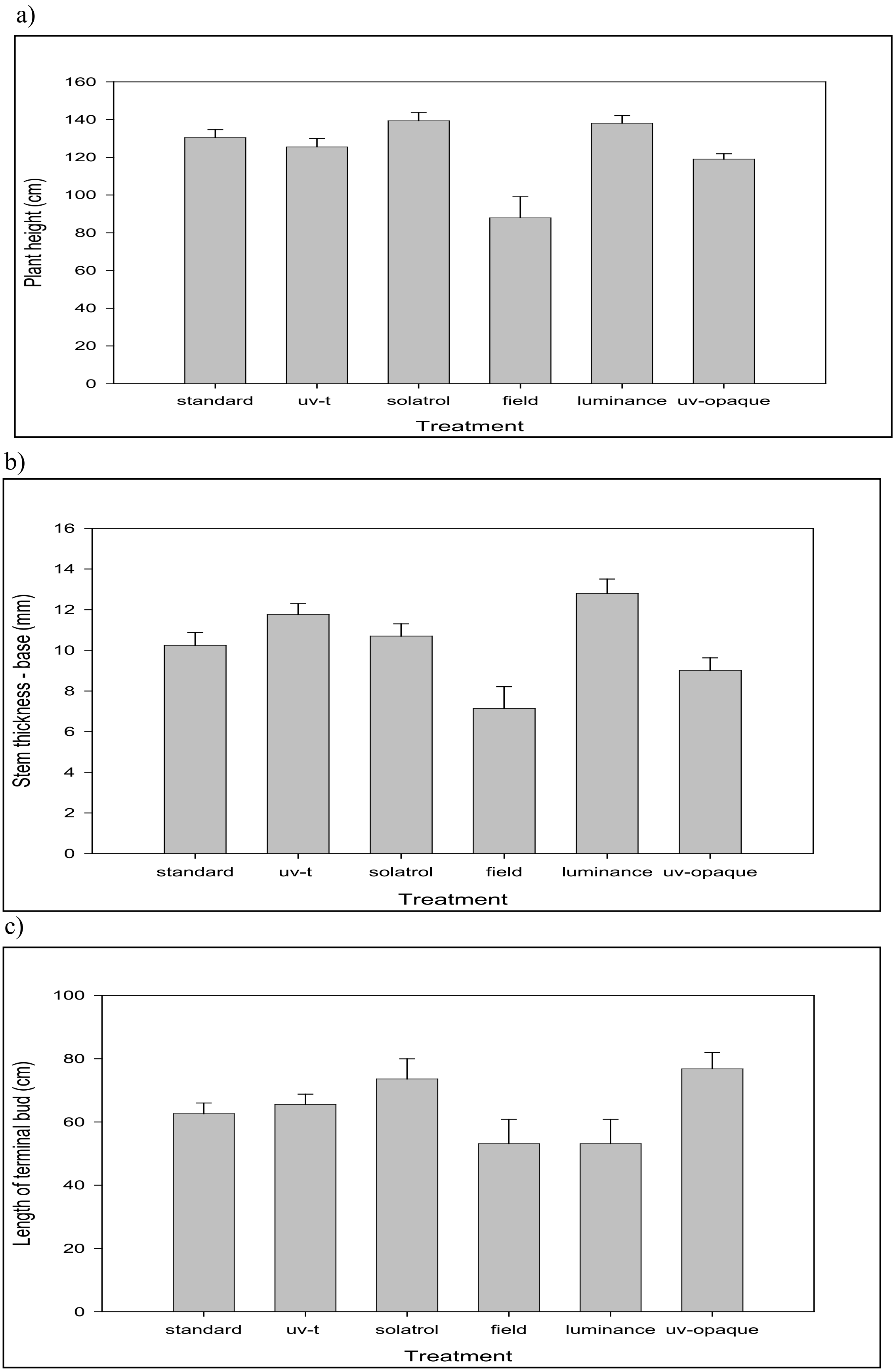


Figure 17. Effect of treatment on (a) plant height (b) stem thickness – base and the (c) length of the terminal inflorescence in *Delphinium* cv "Black Knights". Each value is the mean ± S.E. of 10 replicates.

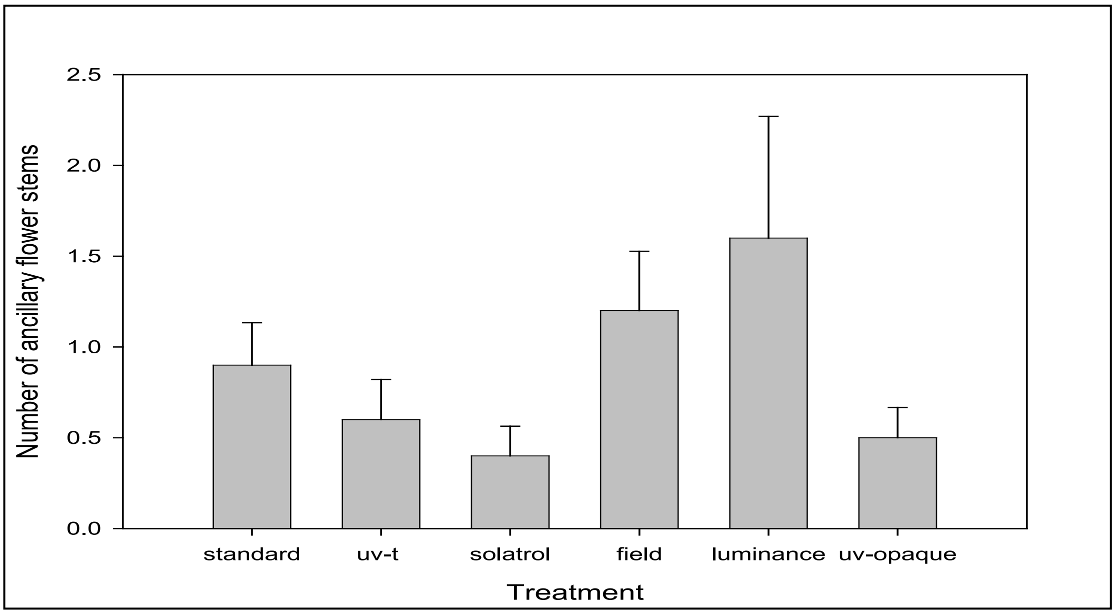


Figure 18. Effect of treatment on number of ancillary breaks. Each value is the mean ± S.E. of 10 replicates.

RED ASTERS

Plant height was significantly greater in plants grown under Solatrol and significantly less in plant grown under UV-transparent than in other treatments (Fig. 19). Basal stem thickness was significantly greater in field-grown plants than in all other treatments except Solatrol (Fig. 20.a). There were no significant effects of treatments on the number of primary (basal) branches (data not shown). Compared with the Standard film, the number of secondary branches, or ancillary breaks, was significantly increased in plants grown under Luminance and UV-opaque, but not under solatrol or UV-transparent (Fig. 20.b). Flower (capitulum) diameter was significantly increased in plants grown under UV-opaque film compared to Standard film, Luminance and the Field, but not compared with UV-transparent and Solatrol (Fig. 20.c).

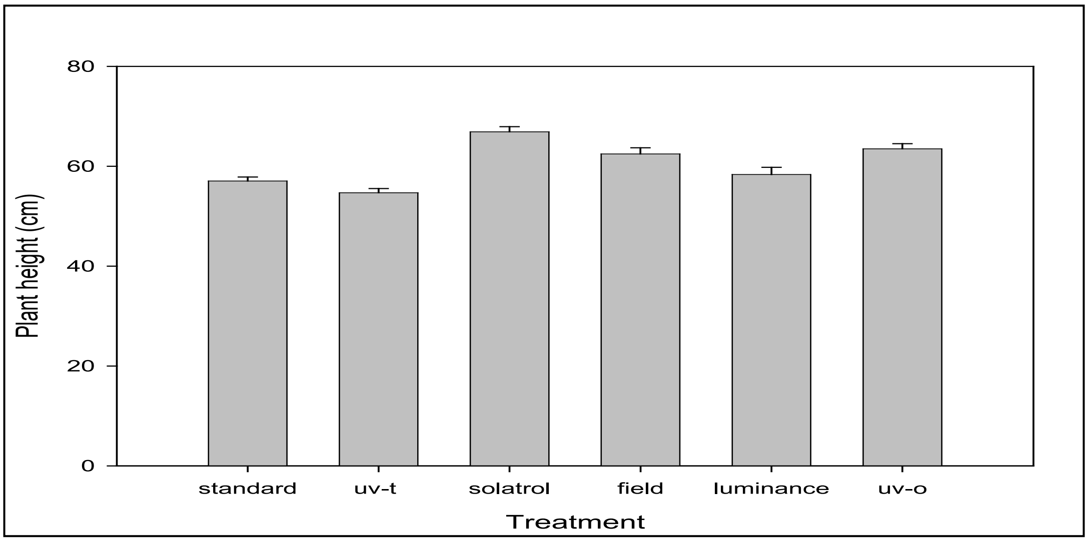


Figure 19. Effects of treatment on plant height in red Asters. Each value is the mean ± S.E. of ≥ 34 replicates.

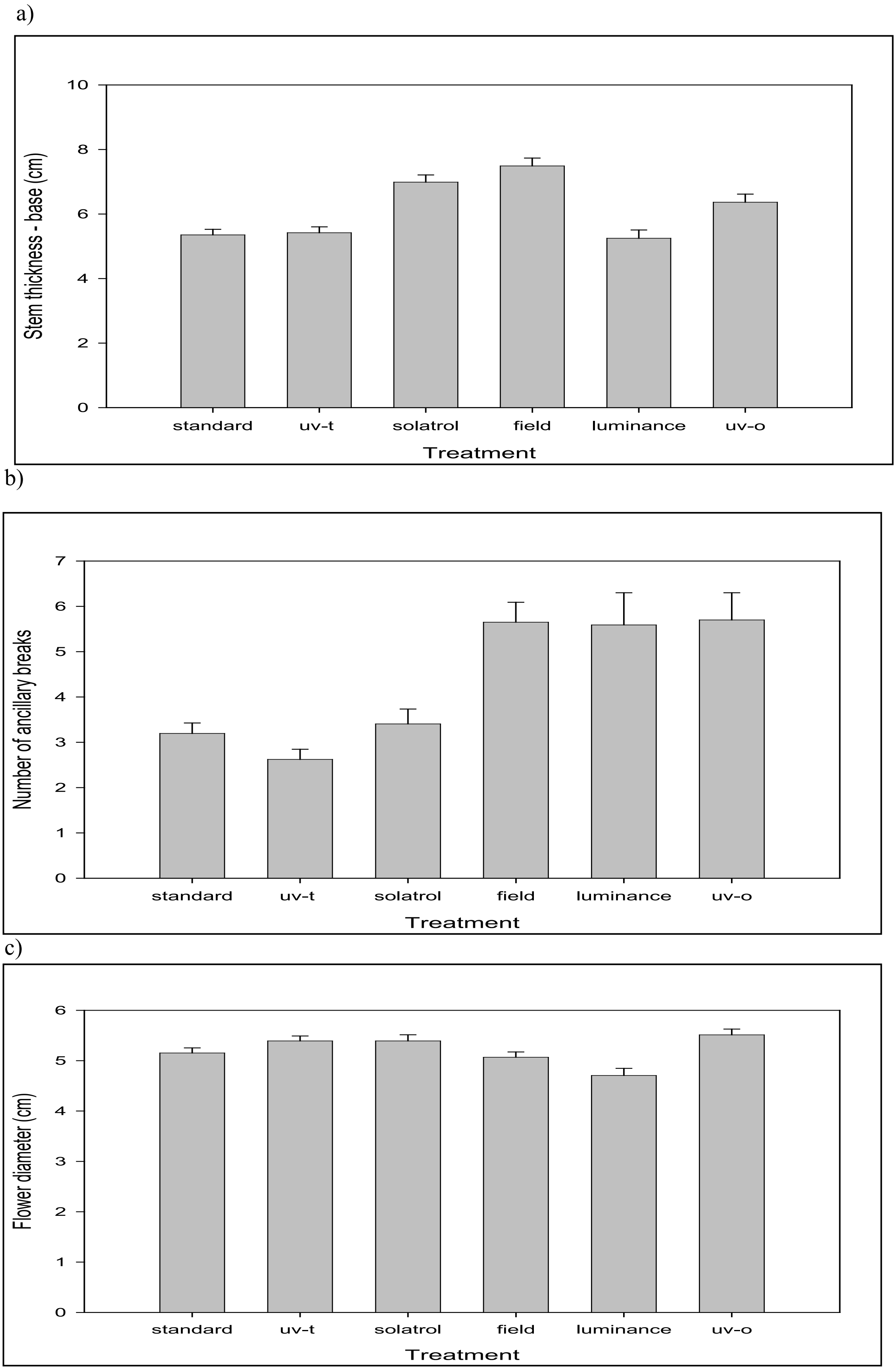
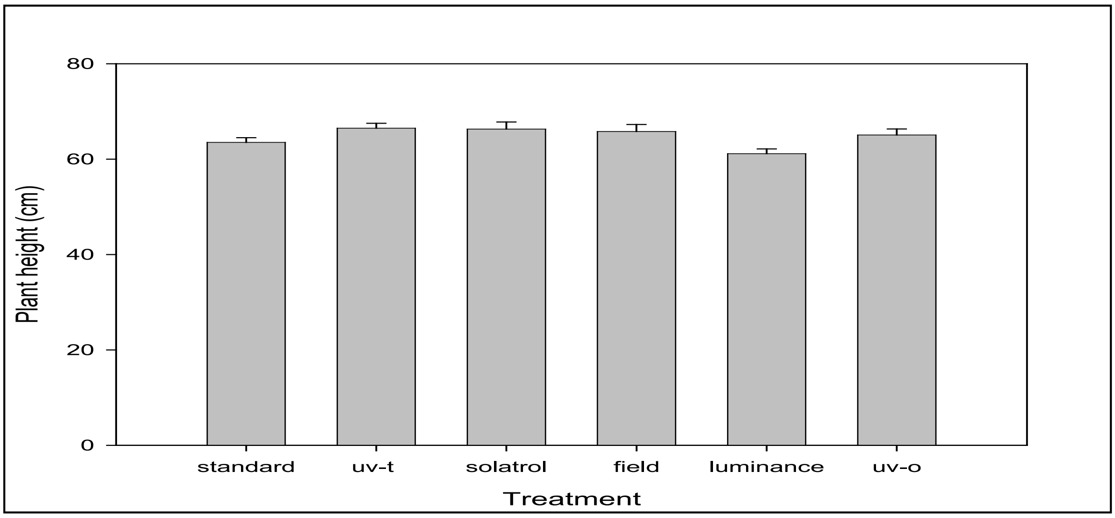


Figure 20. Effects of treatments on (a) stem thickness – base (b) the number of ancillary breaks and (c) flower diameter in red Asters. Each value is the mean ± S.E. of ≥ 34 replicates.

PURPLE ASTERS

Plant height was significantly reduced under Luminance compared to the UV-opaque, UV-transparent, Solatrol filters and Field grown plants (Fig. 21.a). Basal stem thickness was significantly greater in field plants compared to all filter treatments (Fig. 21.b). Also, stem thickness was reduced in Luminance relative to UV-opaque, Standard, UV-transparent, Solatrol and Field plants (Fig. 21.b). The diameter of the flower was significantly greater in Field plants when compared to UV-transparent and Solatrol only (Fig. 22.a). There was also a significant increase in ancillary breaks in Standard when compared to Field plants and all film treatments (Fig. 22.b).

a)



b)

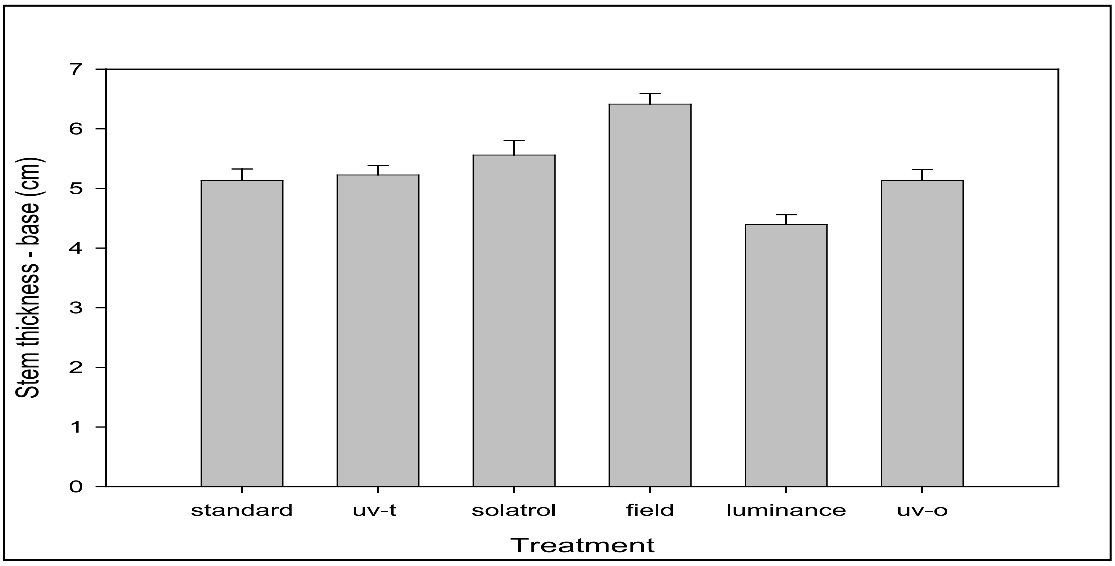


Figure 21. Effects of treatment on (a) plant height and (b) basal stem thickness in purple asters. Each value is the mean + S.E. of > 29 replicates.

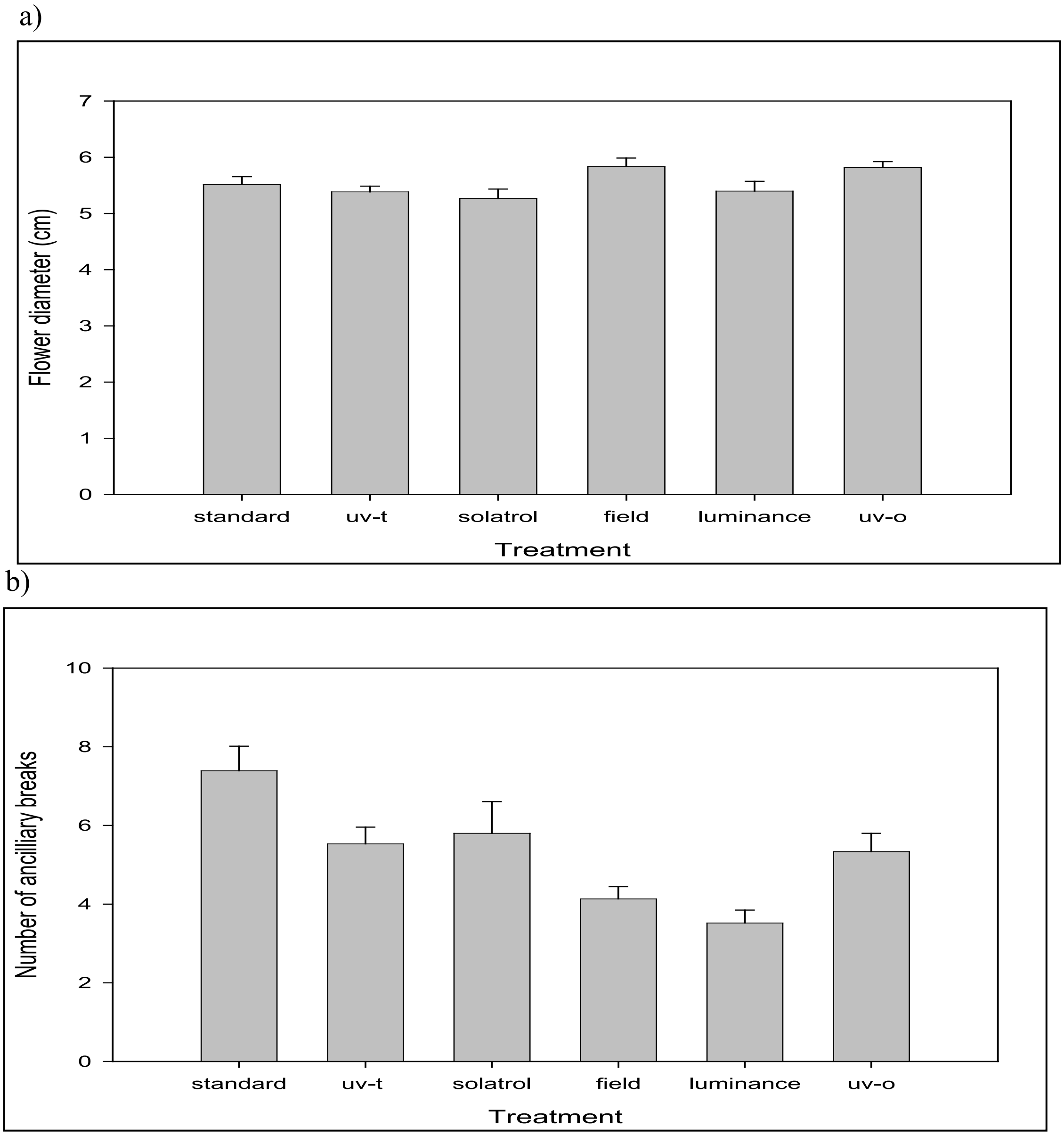


Figure 22. Effects of treatment on (a) flower diameter and (b) number of ancillary breaks in purple Asters. Each value is the mean ± S.E. of ≥ 29 replicates.

WHITE ASTERS

Plant height was significantly increased in Field grown plants when compared to all filter treatments except Solatrol (Fig. 23.a). Basal stem thickness was significantly greater in Field plants when compared to Luminance, UV-opaque, Standard and UV-transparent films, but not Solatrol (Fig. 23.b). Flower diameter was significantly increased in UV-opaque when compared to Standard, Solatrol and field only (Fig. 23.c). The number of ancillary breaks was greater under the Standard film relative to UV-transparent, Solatrol, UV-opaque and Field grown plants, but there was no effect when compared to Luminance (Fig. 24.). Also, the number of ancillary breaks were significantly reduced in Solatrol when compared to Field, Luminance, UV-opaque and Standard, although there was no significant effect relative to UV-transparent (Fig. 24).

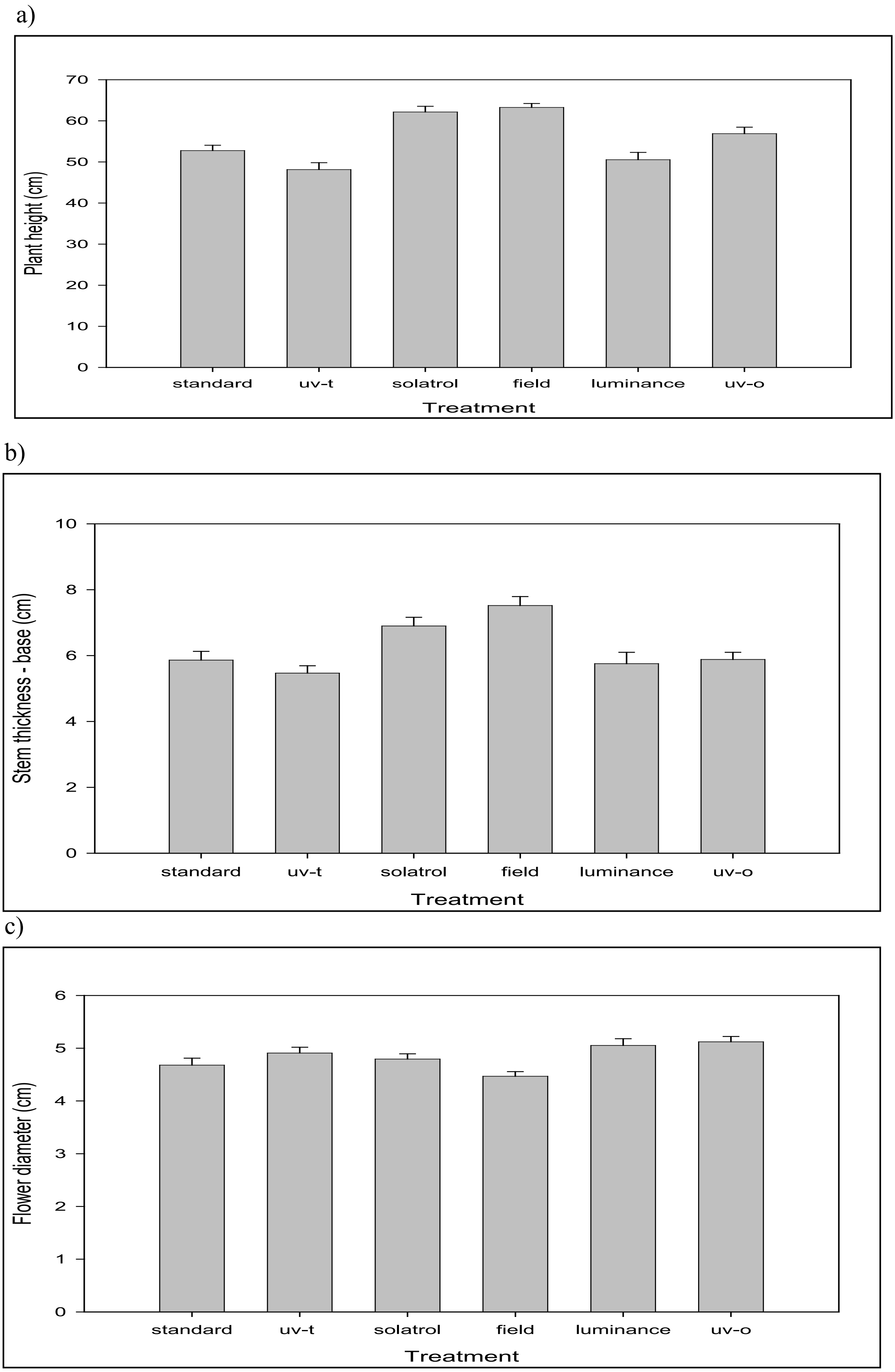


Figure 23. Effects of treatment on (a) plant height and (b) basal stem thickness and (c) flower diameter in white Asters. Each value is the mean + S.E. of > 17 replicates.

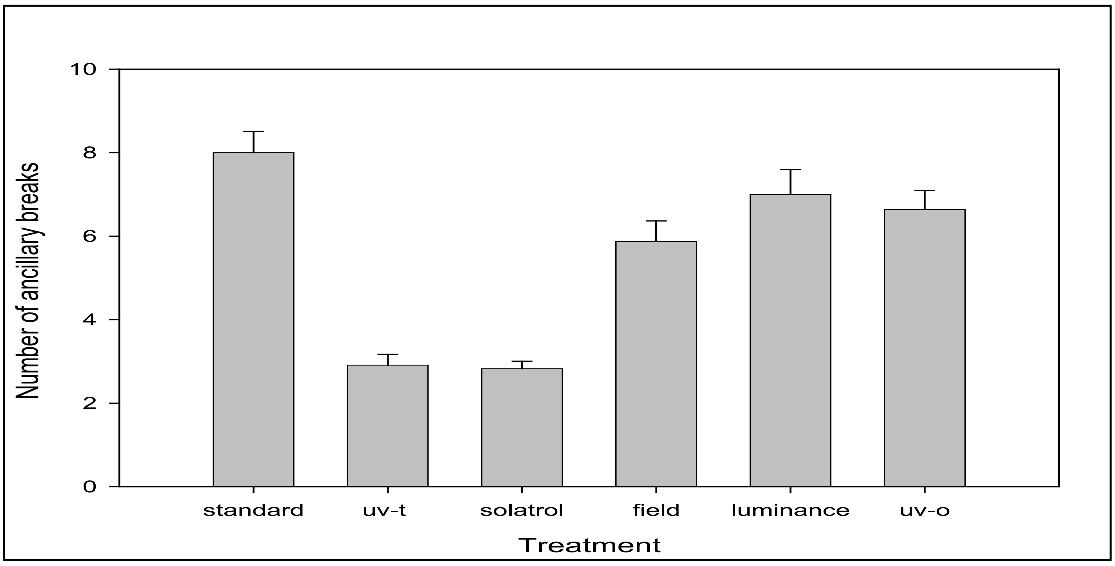


Figure 24. Effects of treatment on number of ancillary breaks in white Asters. Each value is the mean ± S.E. of ≥ 17 replicates.

Discussion

Cut flower producers are coming under increasing pressure from large retailers to both diversify their business and to reduce production costs. One possible way of achieving this is by substituting traditional glasshouse production with large-scale plastic protection. Further ‘added value’ could be achieved if the protective filters were shown to alter crop development in such a way as to increase both the quantity and quality of the marketable product. Results from the first seasons trials suggest that certain cut flower species do indeed respond to altered light regimes in a potentially economically valuable way.

In Stocks there was a general trend for increased length and number of flowers in the terminal inflorescence under the Solatrol filter. Field grown Larkspur produced plants with more pronounced vegetative growth in the form of increased numbers of ancillary breaks, although there was no difference between the plastics (Fig. 7.a).

Results from Delphinium were somewhat more complex. Tentative evidence from the first year’s trial suggests that both terminal inflorescence and ancillary flower numbers were increased under Luminance. There is also evidence in the data to suggest that the length of the terminal inflorescence was generally increased under both Solatrol and UV-opaque. Further work in the 2004 season will seek to clarify these results.

In Asters we observed a clear effect of certain filters on canopy development. Defining canopy development is difficult, but it probably encompasses interactions between break numbers, internode length and total leaf area. Under Luminance and in the open plot (Field), canopy development was visually poor (Fig. 26 & 27). However, Solatrol produced visually deeper canopy development (Fig. 28), which could translate into a more marketable product for retailers through customer perception of more attractive foliage and increased plant weight, which helps gives the ‘feel’ of value.

Perhaps more interesting than the spectral filters effects on vegetative development were the structural and colour changes observed in Aster. In the open plot (Field) and under the UV-transparent filter flower colouration was visually more intense (Fig. 28). However, structural changes in the flower head may offset any colouration effects, or indeed enhance them, depending on personal choice. The precise nature of these changes, and the mechanisms that underlies them, will be investigated in more detail in future work.

Results from the first years trials suggest that cut flower productivity and quality could be significantly improved by switching to production under spectral filters. However, given that the various economically important responses were species specific more detailed and clearly focused work will be required before any clear advice can be given to growers.

Figure 25. Canopy development in Luminance.

Figure 26. Canopy development in the open plot (Field).

Figure 27. Canopy development in Solatrol.

Figure 28. Flower colouration and structure in Aster.

Acknowledgements

The authors wish to thank Charles Dobney for assistance in sourcing plants for this part of the project. We would also like to thank Stuart Coutts and Simon Crawford for their helpful insights into cut flower production and into the condition of the cut flower market.

Part 6. Hardy ornamental nursery stock (HONS)

Introduction

There has been strong growth in the hardy ornamental nursery stock (HONS) industry over the last decade and this has included an increased interest in production under protection. Where glasshouses are already available, they appear to be the preferred form of protection but elsewhere there is increasing interest in plastic clad tunnels because they require much less capital investment. The latter has created opportunities to use cladding materials that can influence the growing environment by absorbing or blocking certain wavelengths of light.

HONS plants produced from plugs are commonly planted into small pots or liners in late spring or early summer and grown on until autumn when they are re-potted into larger containers. The plants are then trimmed to promote lateral growth and protected from severe weather during the winter. They are usually sold the following spring when they have produced sufficient new growth to form an attractive canopy. This procedure was adopted for this project.

A range of key HONS species (Chamaecyparis, Cotinus, Eleagnus, Photinia, Lavendula, Viburnum, Hebe and Calluna) were obtained as plugs in May 2003 and grown in 9 cm pots on Mypex covered compacted ground. They were irrigated overhead using a lance / rose. All plants were re-potted into 3 litre pots in autumn 2003 and interim assessment was completed. When the cladding was removed from the experimental tunnels in early winter, the plants were transferred to smaller temporary structures clad with the same materials, thus ensuring that the treatments were not interrupted. All plants will be moved back to the main experimental area in March / April 2004 and the final assessment will be made in late spring 2004.

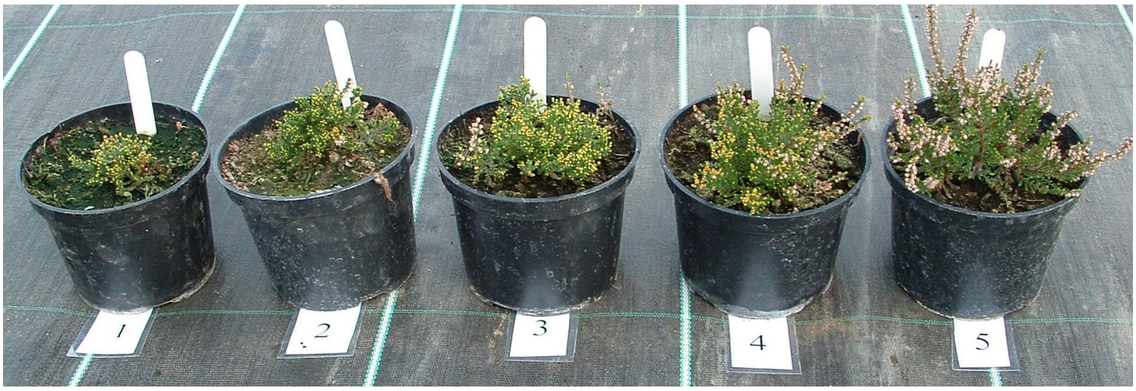
The interim assessment was based on a "marketing index", which has been developed with partners in this project consortium. A score on a 0-5 scale is attributed to each plant; where 0 is dead, 1 is unmarketable, 2 is of borderline marketability (depending on the customer specification) and 3 is acceptable to major retail outlets. 4 and 5 represent quality over and above the basic standard. Photographs of reference standards are provided in the results section.

For all species except Calluna and Erica, root score was also recorded on a 0-5 scale; where 1 represents very little root and 5 is extensive root development. Photographs of reference standards are provided in the results section.

Results

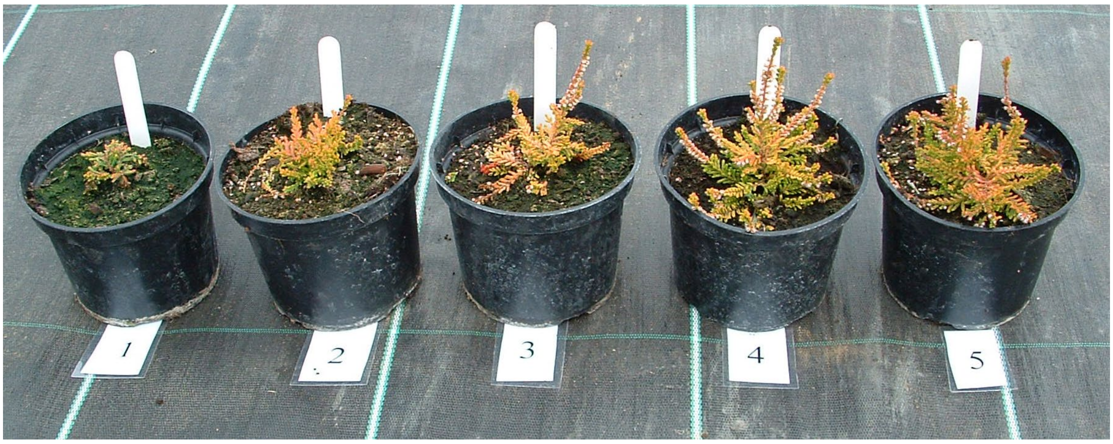
Calluna vulgaris cv. 'Robert Chapman'

	Mean & SD
Plastic	Market index
Standard	4.9 (0.1)
UVT	4.9 (0.1)
Solatrol	1.9 (0.4)
Field	4.6 (0.2)
Luminance	3.6 (0.2)
UVO	3.8 (0.3)



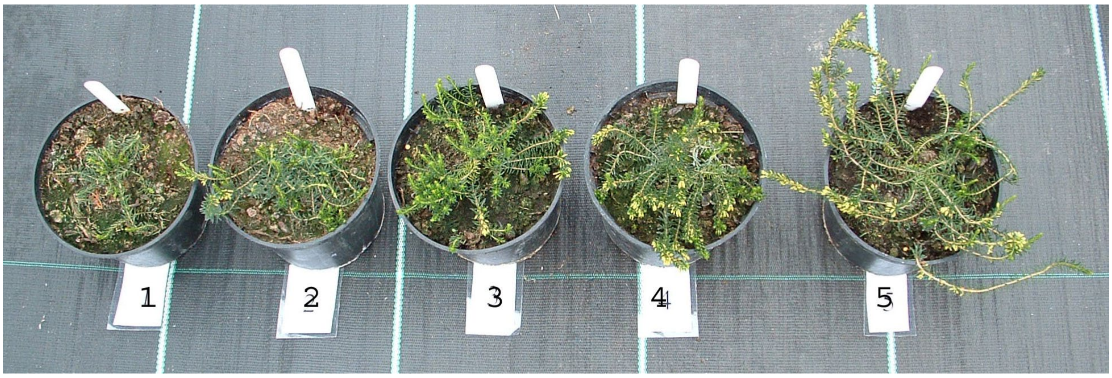
Calluna vulgaris cv. 'Easter Bonfire'

	Mean & SD
Plastic	Market index
Standard	3.7 (0.2)
UVT	3.6 (0.2)
Solatrol	0.8 (0.3)
Field	3.4 (0.2)
Luminance	3.2 (0.4)
UVO	3.2 (0.2)



Erica carnea cv. 'Springwood White'

	Mean & SD
Plastic	**Market index**
Standard	4.9 (0.1)
UVT	4.7 (0.2)
Solatrol	2.5 (0.3)
Field	3.3 (0.2)
Luminance	4.4 (0.3)
UVO	3.8 (0.2)

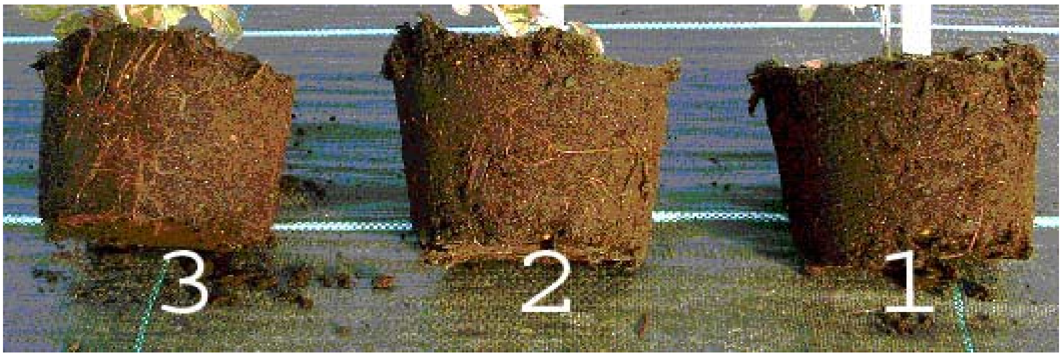


Chamaecyparis cv. 'Ellwoodii'

	Means & SD	
Plastic	**Market index**	**Root index**
Standard	3.3 (0.6)	1.7 (0.6)
UVT	3.6 (0.5)	2.3 (0.3)
Solatrol	3.6 (0.2)	1.4 (0.2)
Field	2.0 (0.0)	2.0 (0.3)
Luminance	4.3 (0.3)	1.4 (0.2)
UVO	3.2 (0.4)	1.3 (0.2)

Cotinus coggygria cv. ‘Royal Purple’

	Means & SD	
Plastic	**Market index**	**Root index**
Standard	3.2 (0.3)	1.6 (0.2)
UVT	2.5 (0.4)	2.0 (0.2)
Solatrol	3.2 (0.3)	2.3 (0.2)
Field	3.1 (0.3)	1.8 (0.1)
Luminance	3.6 (0.3)	2.2 (0.2)
UVO	3.5 (0.4)	1.8 (0.2)



Elaeagnus pungens cv. 'Maculata'

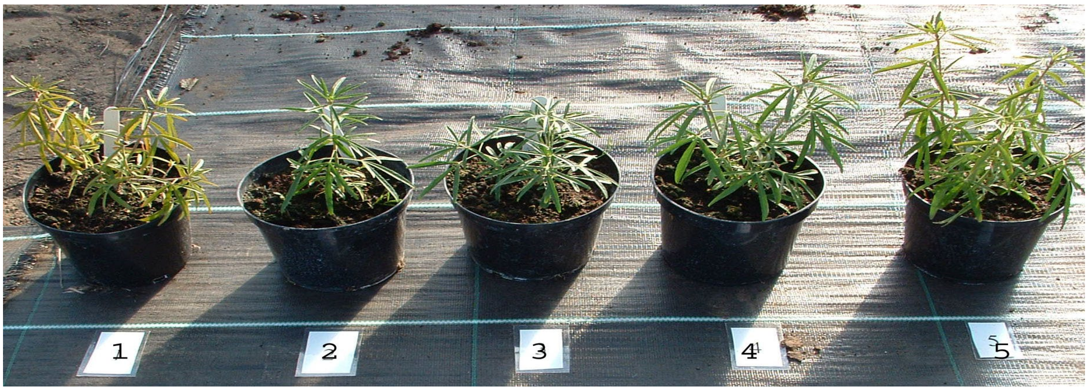
Plastic	Means & SD	
	Market index	Root index
Standard	3.4 (0.2)	3.1 (0.3)
UVT	3.1 (0.4)	2.2 (0.2)
Solatrol	3.2 (0.4)	2.2 (0.3)
Field	3.5 (0.2)	3.5 (0.2)
Luminance	3.0 (0.4)	2.2 (0.2)
UVO	3.1 (0.3)	2.7 (0.2)

Lavendula angustifolia cv. 'Hidcote'

Plastic	Means & SD	
	Market index	Root index
Standard	4.0 (0.1)	4.3 (0.2)
UVT	4.4 (0.2)	3.8 (0.2)
Solatrol	2.3 (0.4)	2.8 (0.2)
Field	3.0 (0.3)	3.6 (0.4)
Luminance	4.0 (0.3)	3.8 (0.2)
UVO	4.6 (0.2)	3.7 (0.2)

Choisya ternate cv. 'Sundance'

Plastic	Means & SD	
	Market index	**Root index**
Standard	3.5 (0.3)	3.4 (0.3)
UVT	2.9 (0.3)	3.3 (0.2)
Solatrol	3.8 (0.3)	4.1 (0.3)
Field	1.1 (0.1)	2.4 (0.2)
Luminance	4.0 (0.3)	3.7 (0.3)
UVO	3.7 (0.2)	3.4 (0.2)

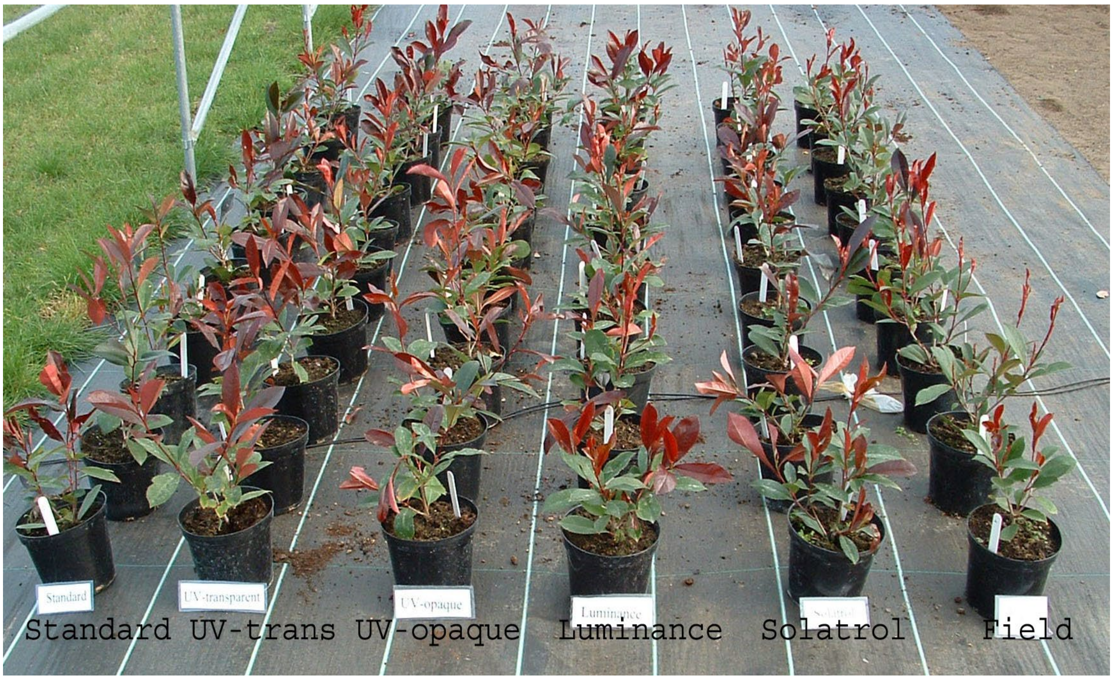


Hebe pinguifolia cv.' Pagei'

Plastic	Means & SD	
	Market index	Root index
Standard	3.5 (0.4)	4.5 (0.2)
UVT	2.4 (0.5)	3.3 (0.4)
Solatrol	2.8 (0.5)	3.7 (0.2)
Field	4.2 (0.3)	3.7 (0.3)
Luminance	2.7 (0.4)	3.8 (0.2)
UVO	3.8 (0.4)	4.0 (0.3)

Photinia X *fraseri cv.* 'Red Robin'

Plastic	Means & SD	
	Market index	**Root index**
Standard	4.3 (0.2)	4.1 (0.2)
UVT	4.5 (0.3)	4.3 (0.2)
Solatrol	3.2 (0.2)	2.9 (0.2)
Field	3.9 (0.3)	4.1 (0.3)
Luminance	4.1 (0.3)	3.8 (0.2)
UVO	4.6 (0.2)	4.2 (0.2)



Viburnum tinus cv. 'Laurustinus'

Plastic	Means & SD	
	Market index	**Root index**
Standard	3.2 (0.4)	2.7 (0.3)
UVT	3.0 (0.3)	2.1 (0.2)
Solatrol	3.9 (0.1)	3.2 (0.2)
Field	3.9 (0.3)	1.9 (0.2)
Luminance	2.7 (0.3)	2.2 (0.1)
UVO	3.5 (0.3)	2.8 (0.2)

Discussion

Interim assessments suggest that Standard, UV-transparent and Field grown plants performed best overall. Standard produced the highest market index ratings for *Calluna vulgaris cv.* 'Robert Chapman', *Calluna vulgaris cv.* 'Easter bonfire', *Lavendula angustifolia cv.* 'Hidcote' and Erica carnea 'Springwood White'. Field grown plants gave the highest market index scores for *Elaeagnus pungens cv.* 'Maculata' and *Hebe pinguifolia* cv.*' Pagei'*. Furthermore, field grown *Calluna vulgaris cv*. 'Calvren' produced more intense vegetative colouration than the remaining five treatments and preliminary observations suggests similar effects in *Photinia* X *fraseri cv*. 'Red Robin'.

Solatrol produced more varieties with the lowest market index. These included *Calluna vulgaris cv.* 'Calvebe', *Calluna vulgaris cv*. 'Calvren', *Lavendula angustifolia cv.* 'Hidcote', Erica ericswe, *Hebe pinguifolia* cv.*' Pagei'* and in *Photinia* X *fraseri cv*. 'Red Robin'. However, Solatrol did produce the highest quality *Choisya ternate cv*. 'Sundance' and *Viburnum tinus cv.* 'Laurustinus'.

Results from the preliminary assessments are complex, with the various varieties responding to the altered light regimes in different ways. In order to maintain those regimes through the winter months we have constructed temporary shelters (using the filters) that will house the plants through until spring. Final assessments will be made in spring 2004.

Acknowledgements
The authors wish to thank Stephen Carter (Needam Growers Ltd and Farplants), John Richardson (Johnsons of Whixley) and Stuart Coutts for assistance in sourcing plants for this part of the project.

Part 7. Herbs

Introduction

Approximately 1,000 ha of herbs are cultivated in the UK and the potential for market growth is considerable since the majority of UK consumed produce is imported from Mediterranean countries. The industry supplies primarily to the food-manufacturing sector, which accounts for 50-60% of total sales (fresh, dried, frozen and volatile oils) and is second only to the retail and catering sector; with a small market developing in the medicinal industry. Herb growers also supply the culinary industry, with the current market valued at approximately 32m and consumption increasing by about 10% per year. Both culinary and medicinal herbs are utilised in the food, cosmetic, pharmaceutical and beverage industries and are currently supplied between a variety of both small and large-scale herb producers throughout the UK.

A wide variety of herbs can be successfully cultivated in Northern Europe, with a number of exceptions, including plants grown for seed production, or plants with specific growth requirements. Incorporating the use of spectral filters into UK herb production may provide several benefits to UK growers. These include standard protection from the unpredictable climate and the ability to time production to more accurately meet market demand. Furthermore, there is preliminary evidence that suggests that a number of new spectral filters modify plant development in such a way as to increase both herb fresh and dry weights, while modifying essential oil production in an economically beneficial way.

Results

FRESH WEIGHTS

LAVENDER
UV-opaque significantly increased plant fresh weights when compared to Standard, UV-transparent, Solatrol, Field and Luminance (Fig. 1.a), while fresh weights were significantly reduced in Field relative to all other treatments (Fig. 1.a).

BLACK PEPPERMINT
In Peppermint, UV-opaque plants exhibited increased fresh weights when compared to UV-transparent, Solatrol, Field and Luminance plants, although there was no significant effect relative to Standard (Fig. 1.b). UV-transparent produced plants with the lowest fresh weights when compared to all remaining treatments (Fig. 1.b).

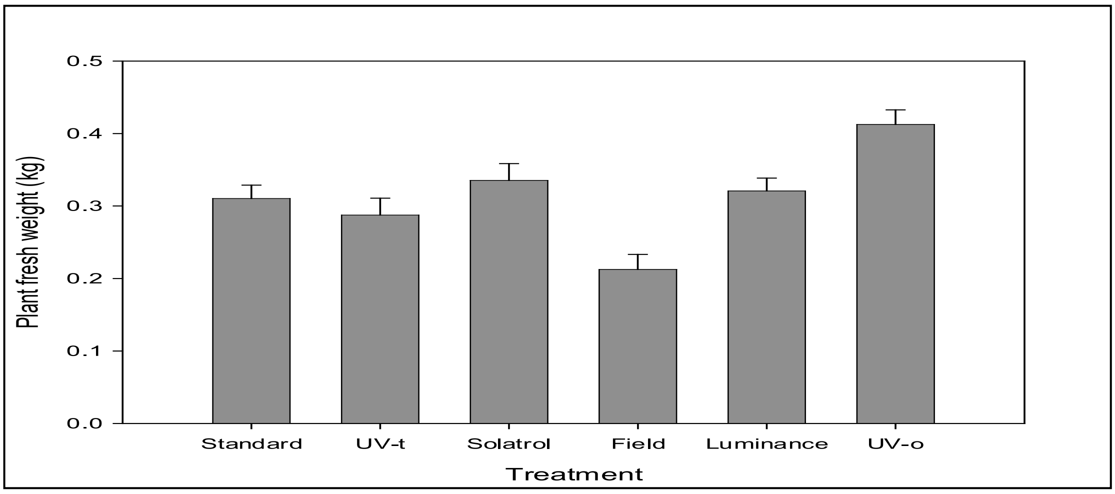
ROSEMARY
Fresh weights were significantly reduced in Field relative to all treatments (Fig. 2.a). The Standard filter produced the highest fresh weights when compared to UV-transparent, Solatrol, Field, Luminance and UV-opaque (Fig. 2.a).

SAGE
The greatest effect of treatments was observed in Field plants, which exhibited highly significantly reductions in fresh weights relative to all five filters (Fig. 2.b). In

contrast, fresh weight was increased in UV-opaque compared to all remaining treatments (Fig. 2.b).

THYME
The Standard, UV-transparent and Solatrol filters, along with Field plants, had similar fresh weights (Fig. 2.c). Both Luminance and UV-opaque filters produced plants with highly significantly increased fresh weights compared to all four remaining treatments, although there was no significant difference between UV-opaque and Luminance (Fig. 2.c).

a)



b)

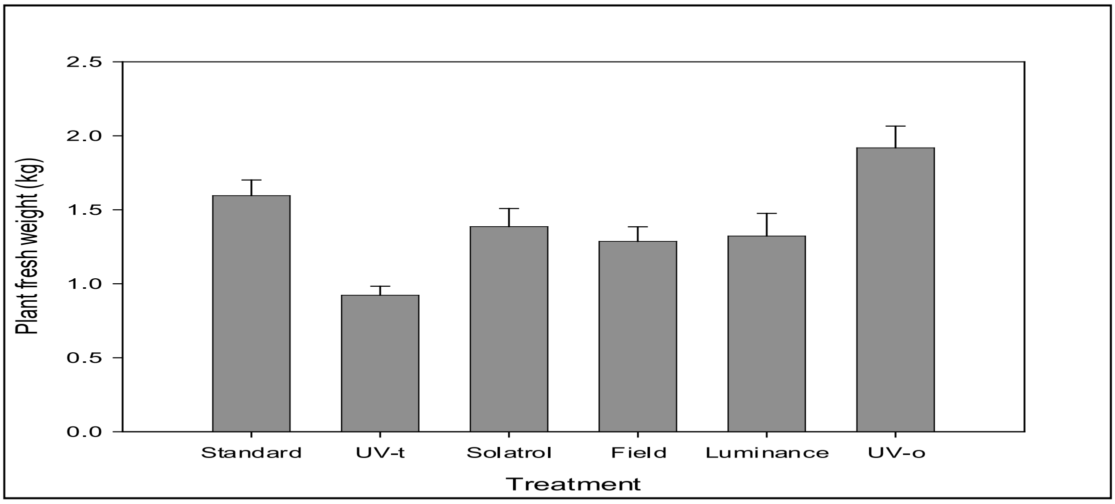


Figure 1. Effect of treatment on fresh weights in (a) Lavender and (b) Black peppermint. Each value is the mean ± S.E. of 19 replicates.

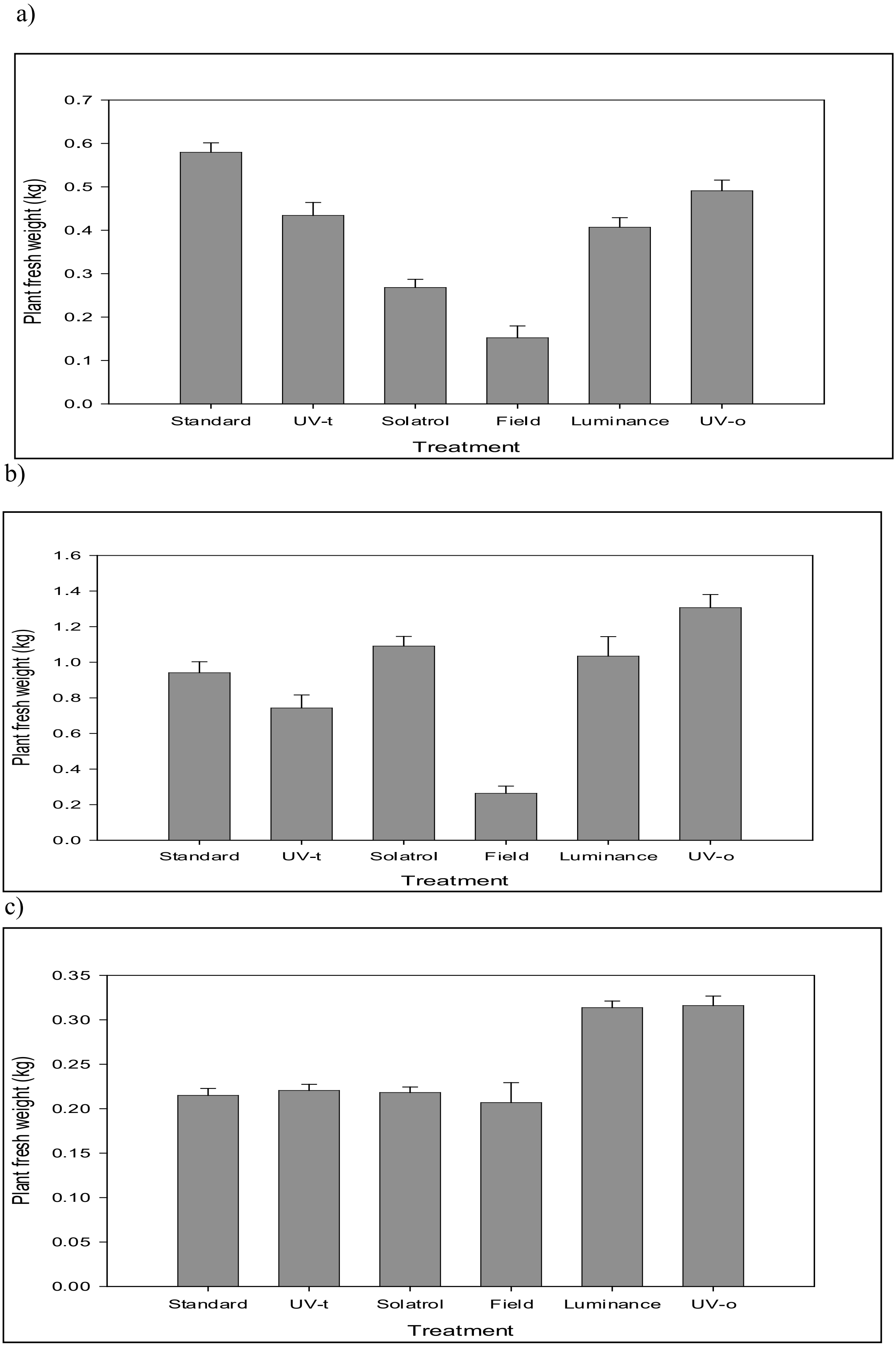


Figure 2. Effect of treatment on fresh weights in (a) Rosemary, (b) Sage and (c) Thyme. Each value is the mean ± S.E. of 19 replicates.

DRY WEIGHTS

LAVENDER
UV-opaque significantly increased dry weights when compared to all treatments (Fig. 3.a) and there was a highly significant reduction in Field dry weights relative to all filters (Fig. 3).

ROSEMARY
Standard increased dry weights when compared to all remaining treatments (Fig. 4.a). There was also a highly significant reduction in Field dry weights relative to all filter treatments except Solatrol (Fig. 4.a).

SAGE
UV-opaque significantly increased dry weights when compared to Standard, UV-transparent, Solatrol and Field, although there was no significant effect relative to Luminance (Fig. 4.b). There was also a highly significant reduction in Field dry weights relative to all filter treatments (Fig. 4.b).

THYME
Dry weights were significantly increased in UV-opaque when compared to Standard UV-transparent, Solatrol and Field, although there was no significant effect relative to Luminance (Fig. 4.c). Field dry weights were significantly reduced relative to all filters except Solatrol (Fig. 4.c).

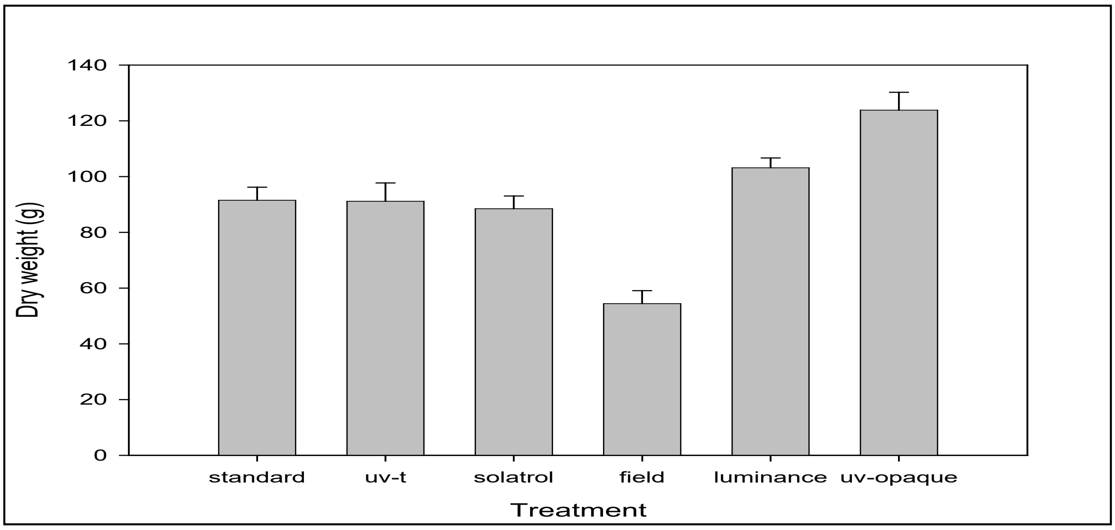


Figure 3. Effect of treatment on dry weights in Lavender Each value is the mean ± S.E. of 19 replicates.

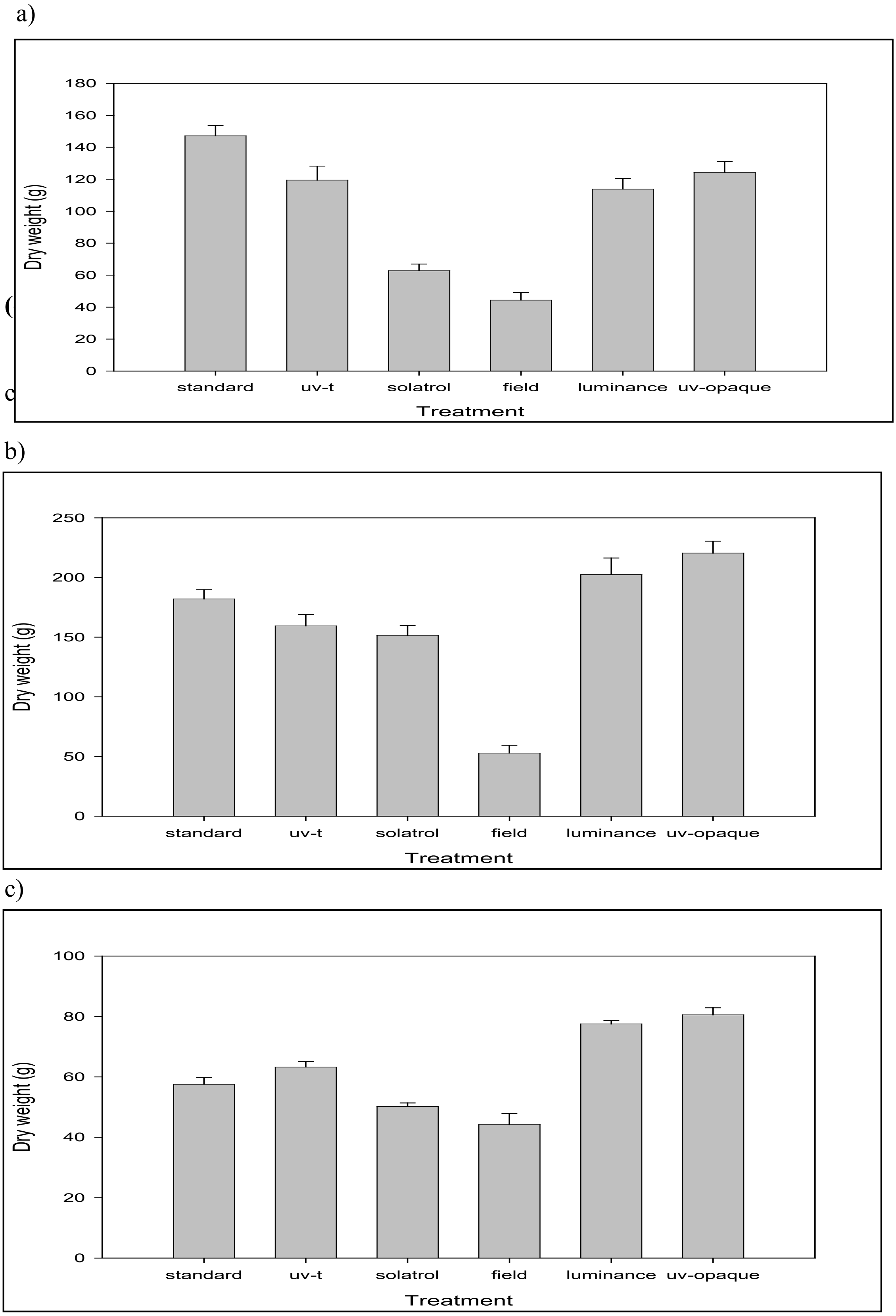


Figure 4. Effect of treatment on dry weights in (a) Rosemary, (b) Sage and (c) Thyme. Each value is the mean ± S.E. of 19 replicates.

OIL CONTENT AND YIELD

Averaged across all plastics and crops, cultivation under the Haygrove structures increased mean oil content by 19±6% (Table 1). There was marked variation between plastics and crops. UV-O gave the highest oil content in thyme and was equal with standard film in rosemary, Luminace gave the highest oil content in sage, and UV-T in peppermint (Table 1). Solatrol gave the lowest oil contents of all the films except in rosemary, and in peppermint and sage oil content under solatrol was lower than that obtained from the field grown plants (Table 1).

Table 1.a Herb Oil Content (oil units per kg fresh weight)

	Black peppermint	Rosemary	Sage	Thyme
Standard	95	110	75	50
UV-transparent	155	80	95	50
Solatrol	75	100	65	40
Field	100	70	85	40
Luminance	90	100	120	50
UV-opaque	80	110	110	60

Table 1.b Oil content as % of that in field grown plants.

	Black peppermint	Rosemary	Sage	Thyme
Standard	95%	157%	88%	125%
UV-transparent	155%	114%	112%	125%
Solatrol	75%	143%	76%	100%
Field	100%	100%	100%	100%
Luminance	90%	143%	141%	125%
UV-opaque	80%	157%	129%	150%

Averaged across all plastics and crops, cultivation under the Haygrove structures increased mean oil yield per plant by 2.76 ± 0.4 fold compared to that obtained in the field (Table 2). There was marked variation between plastics and crops, but in general it was effects of spectral filters on growth that had the greater effect on oil yield than oil content. UV-O gave the highest oil yields in peppermint, sage and thyme, and was second to standard in the case of Rosemary (Table 2). At the other extreme, Solatrol gave the lowest oil yield in peppermint, rosemary and thyme, and with sage was similar to UV-T and standard film, all of which gave far lower yields than Luminance and UV-O (Table 2).

Discussion

Results from the first year's trial suggest that there are significant gains to be made with regards to increasing plant fresh and dry weights by switching production to the UV-opaque filter from, either from outdoor, or standard horticultural cladding production. UV-opaque increased fresh weights in Lavender, Peppermint, Sage and Thyme and increased dry weights in Lavender, Sage and Thyme. Indeed almost all the filters used in the 2003 trial produced increased fresh / dry weights when compared to Field grown plants.

Table 2.a Oil yield (oil units per plant)

	Black peppermint	Rosemary	Sage	Thyme
Standard	152 ± 10	64 ± 2	71 ± 5	11 ± 0.4
UV-transparent	143 ± 9	35 ± 2	71 ± 7	11 ± 0.4
Solatrol	104 ± 9	27 ± 2	71 ± 4	9 ± 0.3
Field	129 ± 10	11 ± 2	22 ± 3	8 ± 0.9
Luminance	119 ± 14	41 ± 2	124 ± 13	16 ± 0.4
UV-opaque	153 ± 12	54 ± 3	144 ± 8	19 ± 0.7

Table 2.b Oil yield as % of that in field grown plants

	Black peppermint	Rosemary	Sage	Thyme
Standard	118%	598%	315%	130%
UV-transparent	111%	326%	315%	133%
Solatrol	81%	252%	316%	105%
Field	100%	100%	100%	100%
Luminance	93%	382%	554%	190%
UV-opaque	119%	507%	641%	229%

Table 2. Oil yield as a) total oil units per plant and (b) as a percentage of that in field grown plants. Each value in Table 2a is the mean ± S.E. of 19 replicates, calculated using replicate fresh weight data but a single, bulked oil analyses for each crop.

Results from essential oil analysis showed that there was no apparent effect of spectral modification on oil composition of the spectral filter treatments (data not presented) but that oil content per unit fresh weight was increased under most films compared to the field (Table 1). Increases in oil content were relatively small compared with those in crop biomass under protection, but these two acting together resulted in total oil yields per plant that were substantially increased in most instances under filters relative to field-grown plants. Compared with the field increases in oil yield obtained by best plastic cladding on Haygrove tunnels were 19% for black peppermint, approx. 500% for rosemary (i..e a 6x increase), 540% of sage (i.e. a 6.4x increase) and 130% for thyme (i.e. a 2.3x increase). Although there were plastic- and crop-specific responses, it was the UV-opaque film that generally producing the highest oil yields (Table 2). However, before any firm recommendations can be given to the industry the results from 2003 will need to be viewed alongside those of subsequent seasons. In addition, possible trade-offs with other agronomic features, such as ease of harvest, re-growth after harvest and pest and disease control will need to fully assessed.

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