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Project leader:	Keiri Swann University of Reading
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Location of project:	University of Reading
Industry Representative:	Richard Harnden
Date project commenced:	01/04/2019

DISCLAIMER

AUTHENTICATION

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

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GROWER SUMMARY

Headline

More efficient high red ratio LED lights are as effective as high blue ratios in driving the yield and photosynthetic rate of out of season strawberries.

Background

There is a high demand for home grown out of season strawberries in the UK. Supplementary lighting facilitates winter glasshouse strawberry production and enables further season extension. Where traditional high pressure sodium (HPS) lights are currently used, LED lights offer an alternative with their greater efficiency and ability to control the spectral output. Blue and red light are the most photosynthetically active regions suggesting that predominant use of these wavelengths would increase efficiency of LED lights for horticultural use. However, the blue: red ratio has significant effects on plant morphology, growth and metabolic processes which consequently impacts on the yield and quality.

Summary

This study aimed to find the optimal blue:red ratio for production of the Junebearer strawberry cv. ‘Malling™ Centenary’ which is widely used in out-of-season glasshouse production in the UK. The experiment included six treatments; four LED treatments with the following blue: red ratios: 5:90, 10:85, 15:80, 20:75 (with the remaining 5% as far-red radiation) with a HPS and unlit treatment as a basis for comparison. The HPS and LED lights were set up to provide equal light intensities of 120µmol m^{-2} s^{-1} measured at pot height using a PAR sensor. LED lights performed as well as the HPS lights and there was no significant difference between the blue: red ratio treatments. The results are discussed in the context of plant spectral light responses and effectiveness of LEDs for supplementary lighting for winter glasshouse strawberry production in a temperate climate.

Financial Benefits

This experiment indicates that using LED lights are as effective as high pressure sodium and that the blue:red ratio of light has no significant effect on the yield outcome. LEDs use up to 2.7 times less energy and have a 5 times longer lifespan than HPS lighting decreasing operational costs. The setup of LED systems is expensive, however, as LEDs are increasingly used in horticulture their price will reduce. Red light is more efficiently produced by LED lights than blue. This work indicates that using high red lights will reduce energy costs without impacting yield.

Action Points

If currently using HPS lighting, consider switching to high efficiency LED lighting. It will, if not now then very soon, be the most economical and environmentally friendly option for glasshouse lighting.

SCIENCE SECTION

Introduction

Supplementary lighting enables season extension in glasshouse strawberry production. Where traditional high pressure sodium (HPS) lights are currently used, LED lights are a possible replacement, with higher efficiency and the option of controlling the spectral output (Higuchi *et al.*, 2012; Liao *et al.*, 2014; Nelson and Bugbee, 2014). Blue and red light is the most photosynthetically active, suggesting that predominant use of these wavelengths would increase plant light use efficiency (McCree, 1971; Muneer *et al.*, 2014). Furthermore, red light is most efficiently produced by LEDs (Massa *et al.*, 2008). Neither red or blue light alone is sufficient for plant growth; other wavelengths are also required to mediate suboptimal morphological and aberrant endogenous effects (Hogewoning *et al.*, 2010; Davis, 2016; Trouwborst *et al.*, 2016; Runkle, 2017). The blue: red light ratio has the potential to significantly affect plant morphology, growth and metabolic processes, which, depending on the crop species and desired characteristics, will affect yield and quality (Kami *et al.*, 2010; Kong and Okajima, 2016). Each plant species has a different response to light, thus making crop specific research essential for effective production.

Strawberries have been successfully produced under LEDs (Hanenberg, Janse and Verkerke, 2016), with research examining fruit yield, quality, and earliness under different blue: red ratios. Firstly, combinations of blue and red light have been found to produce higher yields than either colour light alone (Samuolienė *et al.*, 2010; Choi, Moon and Kang, 2015). However, single source blue or red light has produced successful fruit, with blue light producing higher yields (Nadalini, Zucchi and Andreotti, 2017). Additionally, blue light has been shown to promote earlier flowering in Everbearer strawberries (Yoshida *et al.*, 2016; Magar *et al.*, 2018). Nhut *et al.*, 2003 experimented with 0-30% blue and found that 7:3 red: blue ratio was the best for strawberry plant growth. The findings of Hung *et al.*, 2015 support this with 7:3 red: blue ratio providing the best light treatment for strawberry plantlet production from a broad range of treatment ratios (9:1, 7:3, 5:5, 3:7). Strawberry plantlets exhibited higher growth and truss development under a 19:1 red:blue ratio than 10:1 or 5:1 indicating that higher proportions of red light increases yields (Naznin *et al.*, 2016).

Furthermore, earliness of fruit production is very important in out of season strawberry production to attain higher fruit prices. Temperature is a key factor in crop growth, dormancy breaking and time of flowering. HPS lamps produce significantly more radiant heat than LEDs, which, is likely to influence the earliness of fruiting.

Here we compare the growth, yield, and quality of a commercial Junebearer strawberry cultivar ‘Malling™ Centenary’ under different LED spectral distributions, varying the blue: red ratio, alongside comparative performance under HPS and unlit controls and the responses under all lighting treatments when grown at two different temperatures.

Materials and methods

The experiment was conducted in four glasshouse compartments (3.7 m x 7.0 m) which were individually temperature controlled through heating and venting set points. Data loggers were used to record the average hourly temperature in each compartment (TinyTag Gemini Data Loggers Ltd, Chichester, UK). Six-hundred tray plants of the Junebearer strawberry cultivar ‘Malling™ Centenary’, supplied by R. W. Walpole Ltd, were planted in 2

L plastic pots containing 90:10 mix of coir and perlite. Planting was completed on 6th January 2020. A standard commercial strawberry liquid feed (Strawberry Special, Solufeed Ltd., Barnham, UK) and calcium nitrate (YaraTera CALCINIT, Yara UK Limited., Grimsby, UK) was used to fertigate the plants with additional potassium added at fruiting (Solupotassse, Solufeed Ltd., Barnham, UK). pH and EC were set at 5.5 and 1.8 mS/cm respectively and plants were irrigated to 10-20% daily run-off. Biological control for glasshouse western flower thrips (*Frankliniella occidentalis),* two-spotted spider mite (*Tetranychus urticae*), white fly (*Trialeurodes vaporariorum*) and a range of aphid species were also introduced regularly (Bioline Agrosciences, Little Clacton, UK). Bees were introduced every six weeks for pollination.

Six lighting treatments, 4 blue: red ratios of LEDs (20:75, 15:80, 10:85 and 5:90) with additional 5% far red, unlit and HPS, were replicated twice at two temperatures (four compartments). Treatments were established on 6th January 2020 using Greenhouse Toplight Research Modules (Product ID - TUAS OA TS, Tungsram, Budapest, Hungary) and standard HPS lighting units. The lighting was provided for 16-hrs (5am to 9pm) and lights were hung at a distance to provide 120µmols m^{-2} s^{-1} at plant height to replicate levels which are typically used in commercial glasshouse production. The compartment temperature treatments had average temperatures of 17.4°C and 20.3°C. Each compartment contained 25 plants per treatment (lamp) in a grid of 5 x 5. The central 9 plants were tagged to collect data on plant growth, fruit yield and fruit quality whilst the remaining 16 plants were treated as guards.

Yield data were collected biweekly per plant. Fruit were categorised into Class 1 (over 8g), Class 2 (8g and under) and waste fruit. Fruit quality was recorded on ripe fruit, pooled for each treatment replicate at three harvest dates, 2nd, 4th, and 6th week of fruiting. This was to determine fruit sweetness and flavour. The Brix° (sugar content)/ acid ratio was determined using a handheld digital refractometer (PAL-BX|ACID4 Master Kit, Atago, Tokyo, Japan). For the Brix° measurement, 1ml of the fruit juice was placed on the refractometer and the Brix° was recorded. For the acid content 1ml juice was diluted with 50ml of deionised water, mixed, and then placed on the refractometer with the acid content expressed as percentage of citric acid. Measurements of photosynthesis were carried out using an infra-red gas analyser (LCpro-SD portable photosynthesis system, ADC BioSientific Ltd, Hoddesdon, UK) to ascertain if there was any significant link between these physiological measurements and other aspects of the plant growth and cropping performance. Photosynthesis data were recorded from all test plants on an overcast afternoon. For each recording, the leaf chamber was attached to the leaf for at least two minutes for all the values to stabilise before the recording was taken. Statistical analysis was carried out using ANOVA followed by Bonferroni multiple comparison test (Genstat, 18th edition) with the least significant difference at 5%.

Results

The Class 1 yields under the HPS and LED light treatments were similar with significantly lower yield under the unlit treatment (*p*=0.001) (Figure 1). There was an overall reduction in fruit yield in the warm temperature treatment compared to the cool treatment (*p*<0.003) especially under the HPS and 15:80 light treatments (*p*=0.007) (Figure 1).

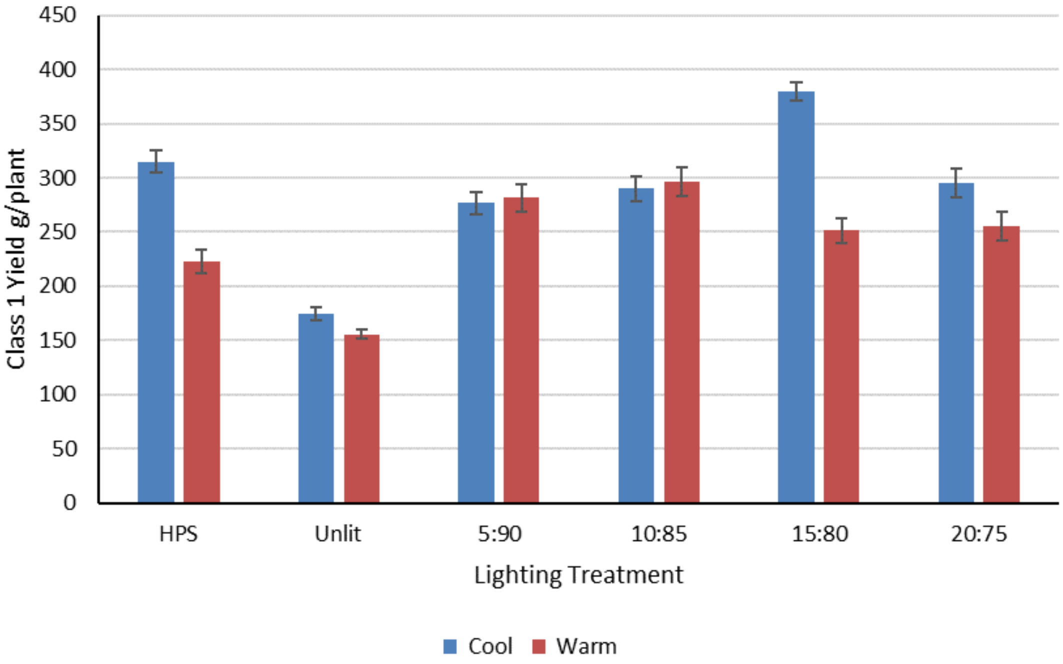

Figure 1: Total Class 1 yield under each light treatment at warm (20.3C) and cool (17.4C) temperatures. The significant differences between light treatments are signified by the lettering above the bars. Vertical lines on each bar represented ±SEM.

The fruit quality for each treatment combination is shown in Table 1. In the cool temperature treatment, fruit produced under the LED lamps had similar Brix° regardless of the blue: red ratio, Brix° increased under the HPS and declined under the unlit treatment. The warm treatment had a higher Brix overall than the cool. In the warm treatment there was no specific effect of LED treatments on fruit quality and the unlit treatment had a higher Brix° than the HPS.

Table 1: Brix acid ratios across light treatments and temperatures. P-values are shown at the bottom of the table.

Treatments		**Brix**	**Acid**	**Ratio**
Cool	HPS	7.36	0.44	16.89
	Unlit	5.83	0.43	13.65
	5:90	6.92	0.45	15.78
	10:85	6.95	0.43	16.26
	15:80	6.85	0.45	15.44
	20:75	7.06	0.46	15.69
Warm	HPS	6.40	0.44	14.76
	Unlit	7.65	0.46	16.94
	5:90	7.27	0.50	14.61
	10:85	8.01	0.50	16.31
	15:80	8.10	0.50	16.20
	20:75	6.57	0.47	14.25
P values		P<0.001	P<0.002	P=0.003

Weekly yields under each light treatment are shown in Figure 2. Yield profiles under the lighting treatments were generally similar with a lower and slower profile for the unlit control.

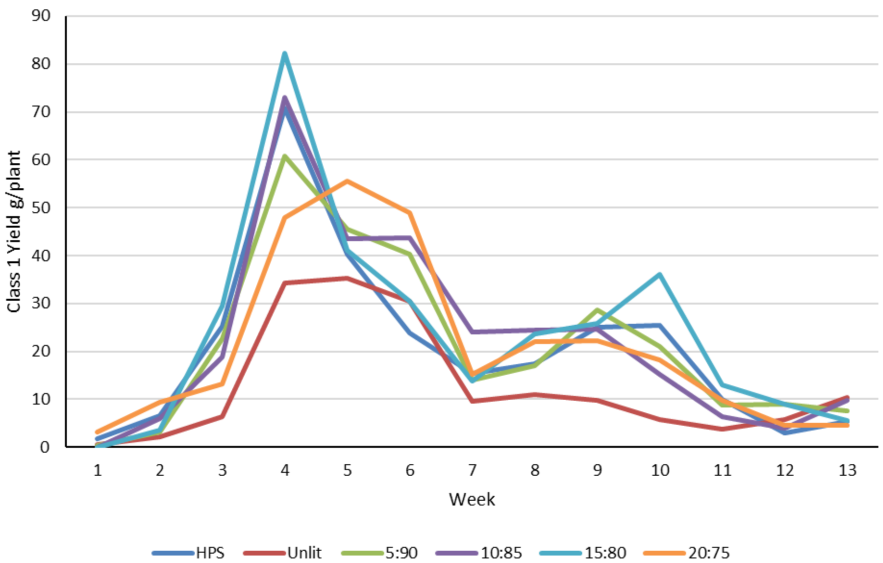

Figure 2: Weekly Class 1 yield from the first to final week of picking under four blue: red LED ratios compared to HPS and unlit controls.

Weekly Class 1 yields under the temperature treatments are shown in Figure 3. The warm treatment yielded earlier fruit, however, due to its larger average berry size the cool treatment caught up and subsequently produced a higher overall yield.

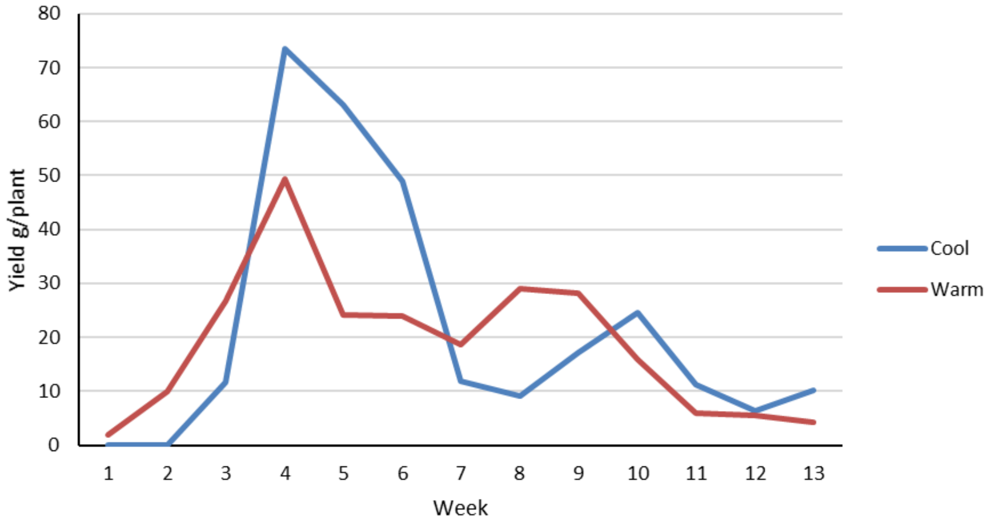

Figure 3: The effect of cool and warm temperature treatments (17.2, 20.3°C) on the weekly Class 1 yield from the first to final week of picking.

The date of flowering indicates crop earliness. The warm treatment flowered on average approximately 7 days earlier than in the cool environment. Flowering under the light treatments were generally similar, whilst the unlit treatment was slightly delayed.

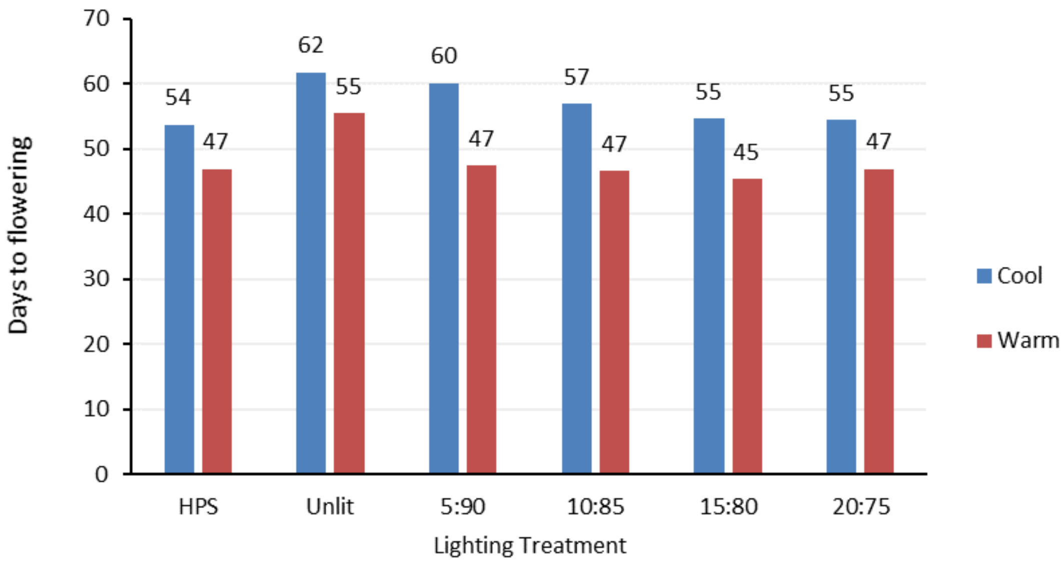

Figure 4: Days from planting to flowering under four blue: red LED ratios compared to HPS and unlit controls at a warm and cool temperature treatment (17.2, 20.3°C). Data labelled on bars.

Photosynthetic rate was significantly lower in the unlit treatment (P<0.001)(Figure 5). There were no significant differences between the other light or temperature treatments.

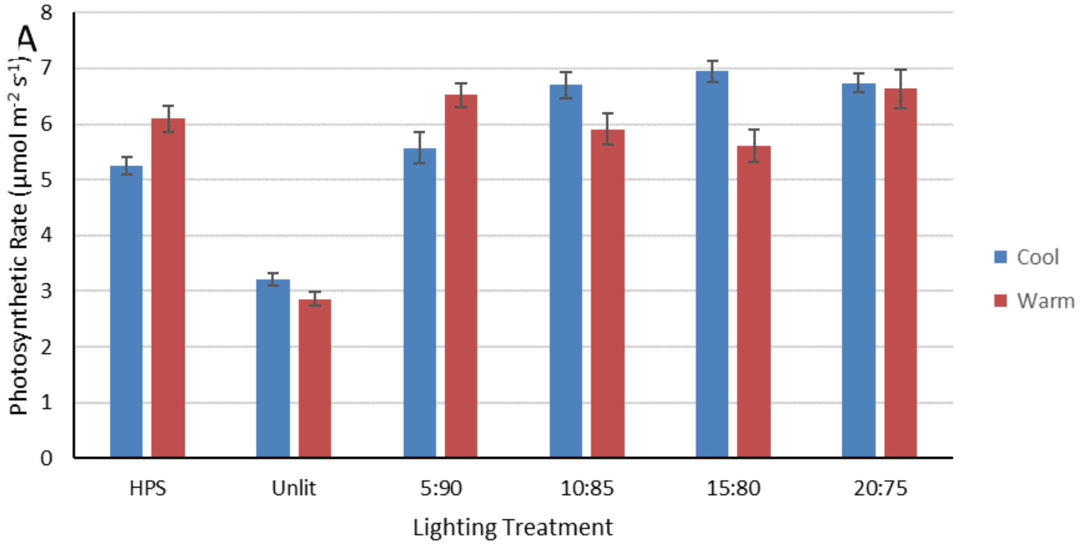

Figure 5: The photosynthetic rate under four blue: red LED ratios compared to HPS and unlit controls at a warm and cool temperature treatment (17.2, 20.3°C). Treatments labelled on bars.

Conclusions and Discussion

The yield obtained was similar to the industry standard for 'Malling™ Centenary' glasshouse production (377g/plant)(Meiosis and Delphy, 2018). Previous research has suggested that varying the blue: red ratio has significant effects yield and plant growth (Nhut *et al.*, 2003; Hung *et al.*, 2015; Naznin *et al.*, 2016; Yoshida *et al.*, 2016; Magar *et al.*, 2018). However, in this study the blue: red ratio of the LED lamps had little effect on the photosynthetic rate, earliness, yield or fruit quality. This suggests that the plants were able to utilise the light ratios equally. As with Hanenberg, Janse and Verkerke (2016), strawberries were grown successfully under LED light, and the photosynthetic rate, earliness and yield were similar between the HPS and the LED light treatments. All the light treatments performed significantly better than the unlit treatment, except from the Brix° in the warm compartment, which was similar to the lit treatments. The warmer temperature treatment accelerated picking by up to two weeks; however, this was accompanied by a reduction in berry size which lowered the overall yield. Additional research could be conducted to examine methods of improving earliness, using temperature without negatively affecting the yield and through other methods such as nightbreak lighting and provision of additional far-red light. The same earliness was achieved under LEDs in the warm compartment as under HPS lamps in the cool compartment indicating that with the same temperature and light intensity the plants perform equally under both light types. From this study it can be concluded that LED lights are a suitable replacement for HPS and that the ratio of blue: red light is not critical for strawberry production.

Knowledge and Technology Transfer

- Oral presentation at the ISHS International Strawberry Symposium
- Won a runner up prize in a GCRI desk study competition Titled: *Towards Net Zero Emissions in Protected Horticulture*

- Won the Worshipful Company of Fruitiers prize and presented my work at the National Fruit Show
- Won the David Miller Award and presented my work at the David Miller Award ceremony
- Poster presentation for the ISHS Light in Horticulture Symposium
- Communications with commercial greenhouse growers carrying out trials looking at hybrid lighting

A seminar to University of Reading, School of Agriculture Policy and Development References

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Appendices

Image 1: Experimental set up of tuneable LED lighting units

