Research Report

Evaluation of the use of light emitting diodes (LEDs) in the production of cut gerbera

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Report Date: June 30, 2014 (Final Report)

Funded by the Joseph H. Hill Memorial Foundation, Inc.

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Objective

The main objective of this project was to compare LED with conventional HID supplemental lighting systems for the production of cut gerbera. Of primary importance were to have statistically-valid replication of lighting treatments and to provide identical canopy level photosynthetically active radiation (PAR, $\mu mol \cdot m^{-2} \cdot s^{-1}$) under each lighting treatment.

Preamble

The objective of this project was to evaluate light emitting diode (LED) technology for use as assimilation lighting for the greenhouse production of cut flowers in northern climates, during the normal supplemental lighting season in the northern regions of North America (e.g. Guelph: 43.5500° N, 80.2500° W); which is approximately early November through late March. To maximize the usefulness of the results to the growers, the LED lighting was directly compared to industry standard high pressure sodium (HPS) lighting systems and was done using carefully-designed experimental protocols to ensure a high level of statistical reliability of the results. This collaborative research project involved representatives from the horticultural lighting industry (Lumigrow Inc), greenhouse cut flower growers (Rosa Flora) and researchers from Dr. Youbin Zheng's Environmental Horticulture research group at the University of Guelph.

Gerbera was chosen as the candidate species of cut flower due to its importance in for North American growers and the reliance on supplemental lighting for production between November and March in northern climates.

Trial Setup

Funding for this project was received in September 2013 and experimental setup was immediately begun to prepare our research greenhouse facility for the upcoming supplemental lighting season (ie. Nov. 2013 through March 2014). The greenhouse trial setup activities were more-fully described in the mid-term progress report. In brief, 8 greenhouse benches (4.57 x 1.07 m each) were used for growing three cultivars of cut gerbera (Acapulco, Terra Saffier and Heatwave) using a drip irrigation system. Each bench was equipped with blackout side curtains that were partially closed to eliminate direct spillover of light from adjacent benches.

This trial had two main treatments: High Pressure Sodium (HPS) and Light Emitting Diode (LED) lighting, with each treatment replicated 4 times (ie. 4 benches per treatment). The HPS fixtures were 400W PL2000 (PL Lights, Ontario, Canada) using the DEEP reflectors and Lucalox lamps (LU400; GE Lighting Inc., Cleveland, OH). The LED fixtures were Pro 325 provided by Lumigrow (Novato, CA) which have a combination of red (R, peak 660 nm), blue (B, peak 440 nm), and white LEDs, each with an individual rheostat, enabling modification of overall intensity and spectral output to user-defined specifications.

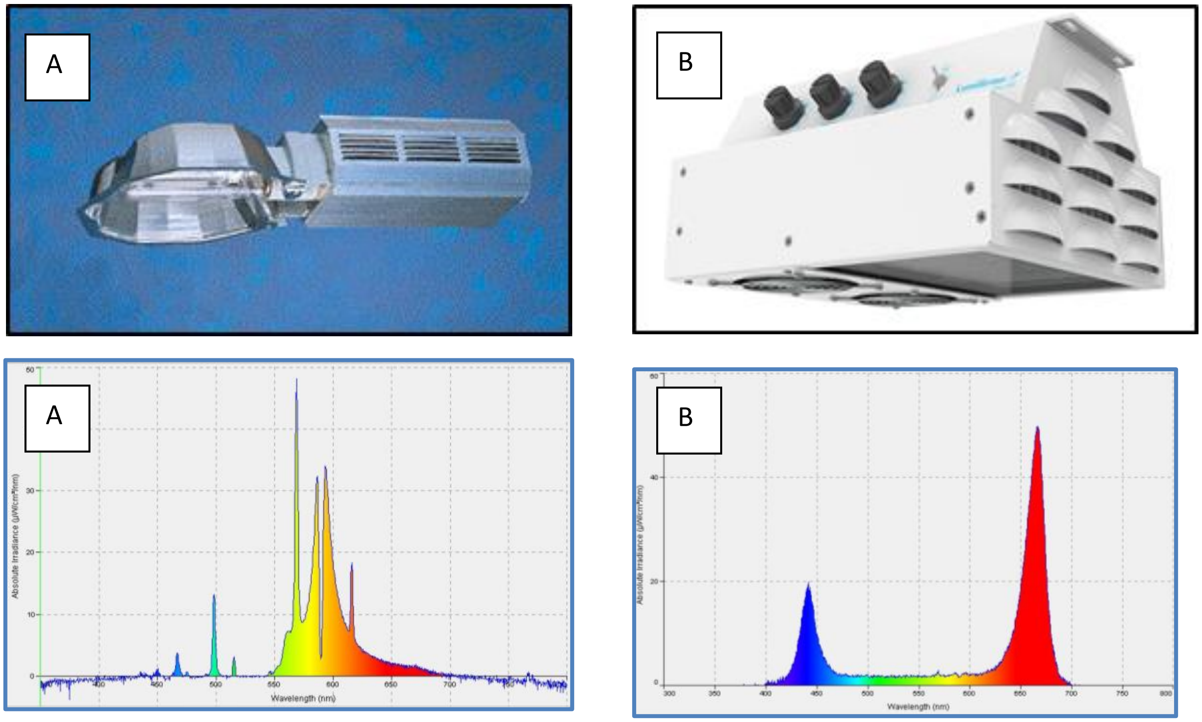


Figure 1 Pictures of the lighting fixtures and their spectral outputs for (A) 400W PL Lights HPS fixture with DEEP reflector and (B) Lumigrow Pro 325 LED fixture

Figure 2 is a picture showing the setup of the crops, the irrigation system and the lighting systems over each bench in the greenhouse (only 4 benches shown). Each bench had 7 pots of each cultivar, spaced evenly (2 rows of 11 pots) with the starting positions randomized. There was one empty position on each bench which was used to facilitate collection of irrigation samples (volume and quality) and to simplify the process of moving pots which was done weekly by rotating each plant one position in the clockwise direction. Weekly pot rotations were done to ensure even light distribution to each plant throughout the trial.

The greenhouse environment parameters were set at similar levels to those at local cut gerbera producers. Supplemental lighting was turned on each day 11 h before dusk and turned off at dusk (ie. 11-h photoperiod). Daytime and nighttime temperatures were set at 21.0 and 16.0 °C respectively. Relative humidity maintained at 70%. Temperature, humidity and PAR sensors were set up at canopy level in the center of each bench and were logged continuously throughout the trial.

Figure 2 Research greenhouse setup showing the growing benches (only 4 visible) with retractable side curtains, the gerbera crop, the drip irrigation system and the lighting systems over each bench.

Each bench had three fixtures of either HPS or LED lights positioned above the benches to provide identical bench-level PAR between lighting treatments and as uniform distribution as possible. The target for canopy level PAR settings was 60 $\mu mol \cdot m^{-2} \cdot s^{-1}$, based on crop level lighting measurements that were made at night at a commercial cut gerbera greenhouse (Rosa Flora, Dunnville, Ontario, Canada). After extensive work to optimize the lighting distribution (all done at night) while maintaining the similar mean bench-level PAR for the two treatments, the final mean bench-level PAR ranged from 53.8 to 56.7 and 55.1 to 58.4 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for the HPS and LED light treatments, respectively. To achieve comparable bench-level PAR, the LED fixtures were positioned roughly 20 cm farther away from crop level and they were turned down to 80% of full power. It should also be noted that while the mean crop-level PAR for both lighting treatments was virtually the same, this is not a true indication of the actual production of PAR from each fixture as they have vastly different beam patterns and the bench-level side curtains effectively 'chopped off' unknown amounts of the light output from each fixture. Overall, the plants received about 5.5 mol m^{-2} day^{-1} with supplemental lighting providing about 2.2 mol day^{-1} (Fig 3).

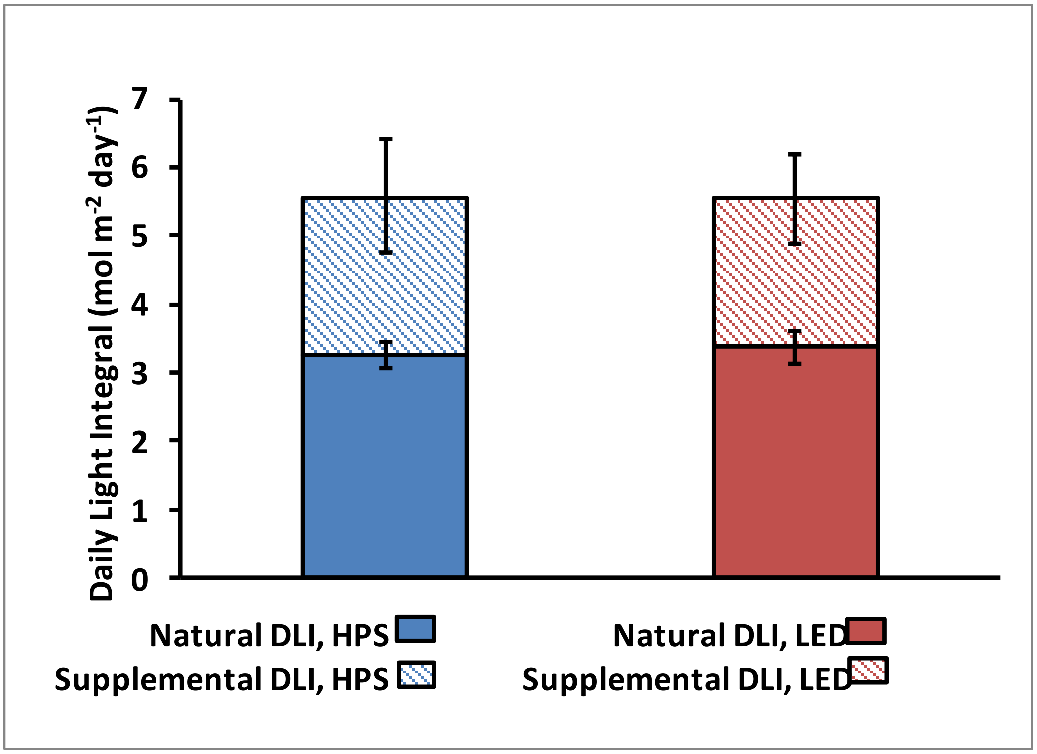


Figure 3 Mean natural and supplemental lighting contributions to total DLI for the LED and HPS treatments

Power Consumption

Power consumption of the different fixtures was determined by measuring the power consumption of one fixture per bench using a KILL A WATT power meter (Model P4400; P3 International, New York, NY). The fixtures had a mean power consumption (n=4) of 257 and 430 W for the LED and HPS respectively (Fig 4). The LED fixtures use 40% less energy than the HPS fixtures in the specific experimental configuration used in this trial. It should be cautioned that an unknown portion of the light output from the fixtures was absorbed by the bench-level blackout curtains or dispersed and did not reach the crops below. Therefore it is not possible to accurately calculate PAR conversion efficiency (ie. $\mu mol_{(PAR)} \cdot W^{-1}$) directly from our data. A true assessment of PAR conversion efficiency would require the use of a light-integrating sphere, of which there are only a few worldwide and they are prohibitively expensive to use, to the point where most lighting manufacturers do not test their own products.

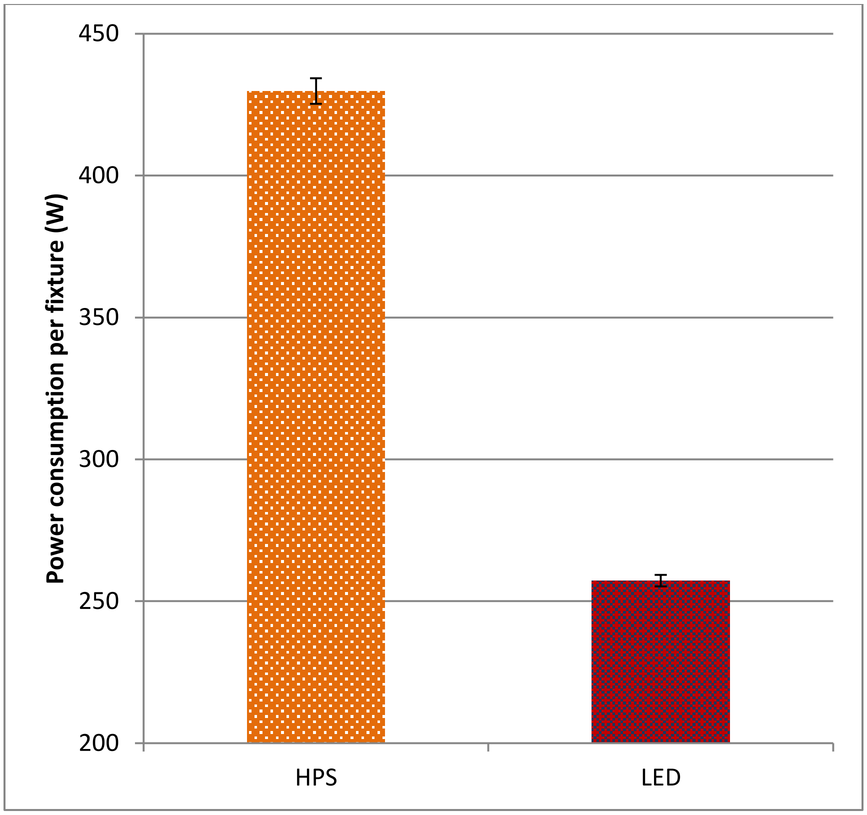


Figure 4 Mean power consumption of the HPS and LED lighting systems, configured in this trial to give equivalent bench level PAR. Note that the LED fixtures were at 80% of full power and located approximately 20cm higher above the benches.

Plant care

The study took place at the University of Guelph in Guelph, Ontario, Canada, beginning on 1 Nov. 2013 and ending on 12 Mar. 2014. All flower stems ≥ 4.5 cm long were removed at the beginning the study. Both supply and leachate water were monitored at least weekly for pH and EC (electrical conductivity) using a portable pH and EC meter (Oakton PC 300; Oakton Instruments, Vernon Hills, IL). Plants were fertigated via pressure-compensated drip irrigation lines (4 $L \cdot h^{-1}$), using a 20N-3.5P-16.6K all purpose high nitrate water soluble fertilizer (pH 5.5, 2208 $\mu S \cdot cm^{-1}$, and 250 ppm N; Plant Products Co. Ltd., Brampton, Ontario, Canada) with temporary substitutions of raw water (pH 7.9 and 1005 $\mu S \cdot cm^{-1}$), when necessary, to maintain an approximate leachate pH of 5.5 and EC of 2500 $\mu S \cdot cm^{-1}$. Pulse irrigation occurred every second day, at 0915 and 1315 HR for 180 s each time. This irrigation protocol was aimed at producing approximately 10-25% leachate, which is in line with commercial cut gerbera production. Hand-watering was used to supplement the drip irrigation, when needed. Various biocontrols were applied as needed for the control of common pests (e.g., thrips, spider mites, and white flies). Additionally, Cease (AgraQuest, Inc., Davis, CA, USA; 20 mL/L), Senator WSB (Engage Agro, Guelph, Ontario, Canada; 0.7 g/L), Compass 50 WG (Bayer Environmental Science Canada, Toronto, Ontario, Canada; 2 g/L) and sulfur buckets (activated between 0100 and 0500 HR) were applied, as needed, to help control powdery mildew.

Leaf Temperature

There was concern that the heat (ie. infrared radiation) that is naturally produced by HPS lighting systems would substantially alter the leaf temperature and the growing environment of the plants in the HPS treatment. A short leaf and air temperature study was performed, in the middle of the trial, to empirically evaluate the influence that the respective lighting treatments had on the growing environment within the particular bench configuration of the greenhouse trial. Leaf and surrounding air temperature was measured on one plant of each cultivar located near the middle of the bench under each of the two lighting treatments (six plants total). A small (2 × 9.5 mm) thermistor (MA100GG103A NTC Thermistor; GE, Lewistown, PA) was attached to the underside of the youngest fully expanded leaf of each tested plant using green paper tape. Leaf temperature was logged at 60-s intervals for 24 h using data loggers (HOBO U12-008; Onset Computer Corporation, Bourne, MA). Figure 5 shows the mean leaf temperatures measured under the LED and HPS lighting treatments. Note that when the lights were off (ie. between 17:00 and 06:00, the leaf temperatures were virtually identical, indicating very homogeneous environmental conditions within the greenhouse. When the lights were turned on the leaf temperatures under the HPS lights increased to a slightly higher level than the leaves under LED. Between 06:00 and 09:00 the mean leaf temperature under HPS was 0.35 °C higher than under LED (17.51 vs 17.15 °C respectively). However, the mean leaf temperatures under HPS during the 11-h daily supplemental lighting period (06:00 to 17:00) was only about 0.05 °C higher than under LED (19.17 vs.19.12 °C respectively). This small difference in daily mean leaf temperature is not expected to result in substantial differences in plant biochemistry (ie. photosynthesis) or gerbera cut flower production.

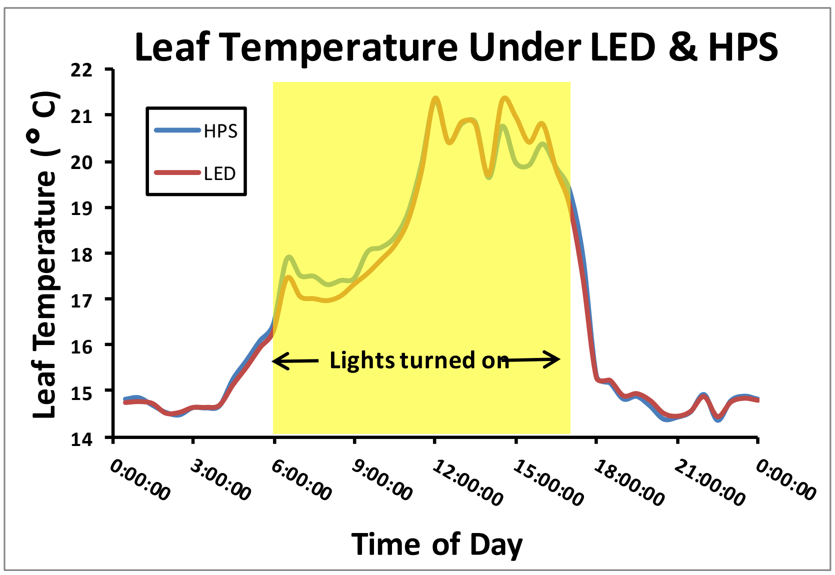


Figure 5. Mean 24-h leaf temperatures under HPS and LED lighting treatments

Cut flower harvesting and quality attribute measurements

Flowers were deemed harvestable once they developed one complete ring of matured anthers. Flowers were harvested three times per week, during which flower diameter, stem length (measured from heel to inflorescence), and fresh weight were measured on each harvested flower. Flower quality was classified subjectively as either marketable or unmarketable according to the severity of malformations and pest and disease damage:

- MARKETABLE FLOWERS: Flower is attractive - any presence of a mutation, powdery mildew, etc. is minor and not easily noticed; flower head is not malformed or is only slightly malformed.

- UNMARKETABLE FLOWERS: Flower is unattractive - too much mutation/discolouration in the centre of the flower; too much powdery mildew in the centre/on petals (is easily noticed); flower head is strongly malformed; flower is stunted. Flowers were considered unmarketable if they met one or more of these criteria.

Flower harvest data is summarized in the following tables and graphs. We compared the harvest metrics for the different *cultivar X lighting treatment* combinations (6), which are summarized in the three graphs in Figure 6. Note that while the error bars are an indication of the variability in the different metrics, non-overlapping error bars are not an indication of statistical significance, in fact Analysis of Variance showed that there were no statistically significant differences, between the two lighting treatments, for any of the harvest metrics. These graphs do demonstrate substantial differences in the harvest metrics between the cultivars. It was expected that fresh weight and flower diameter of Terra Saffier would be lower than the other cultivars because it is classified as a ‘mini’ variety while the other two are ‘standards’. It was not expected that the stem lengths of Acapulco would be lower than the other two varieties, but since the mean stem length was similar for both lighting treatments, it is probably simply a characteristic of the cultivar.

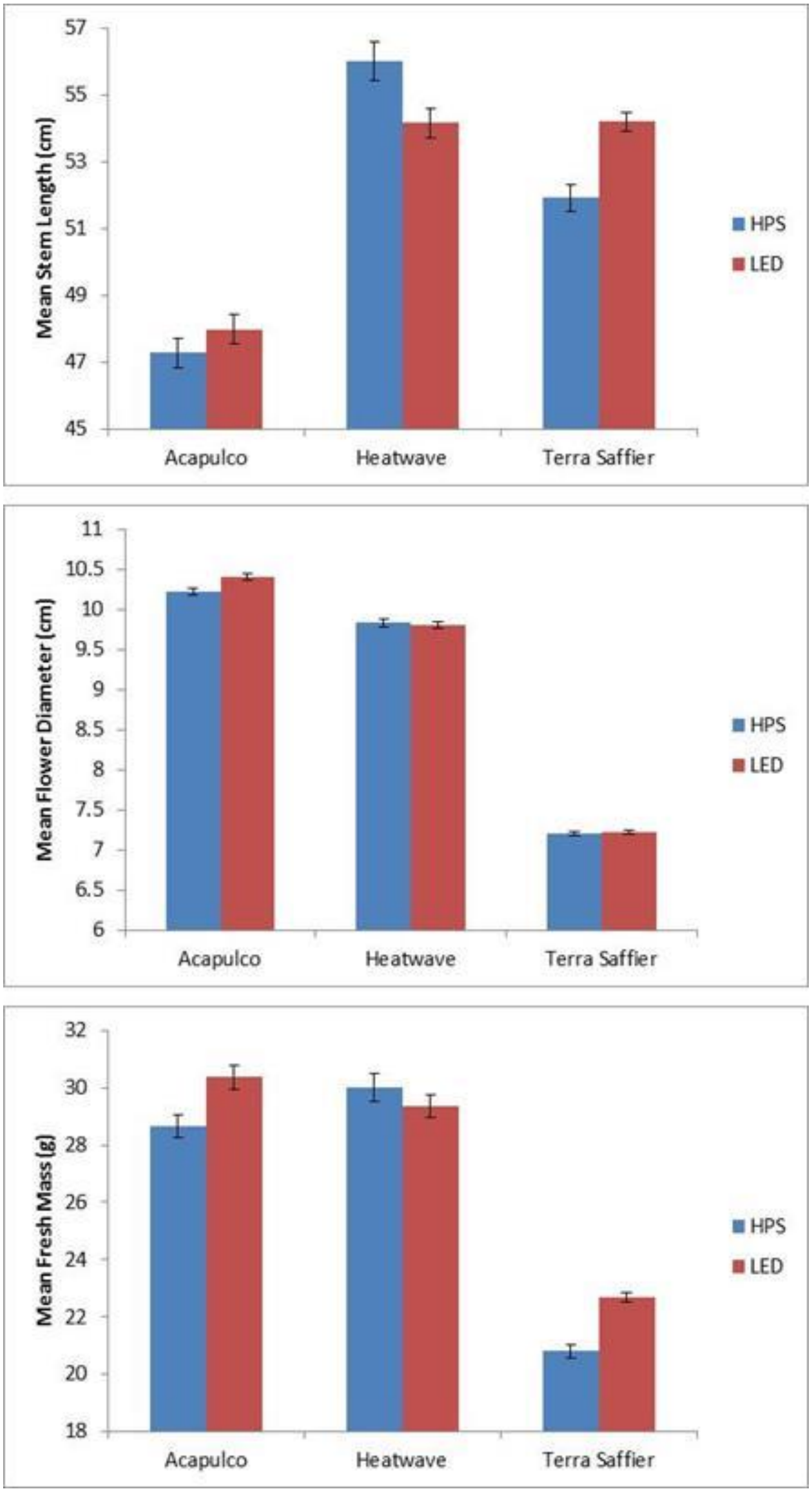
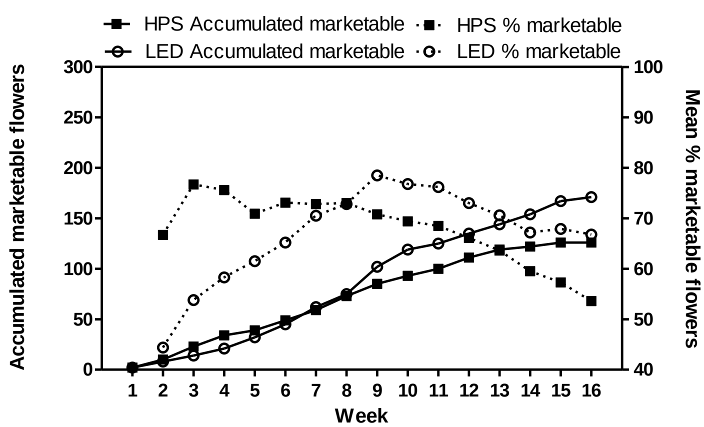


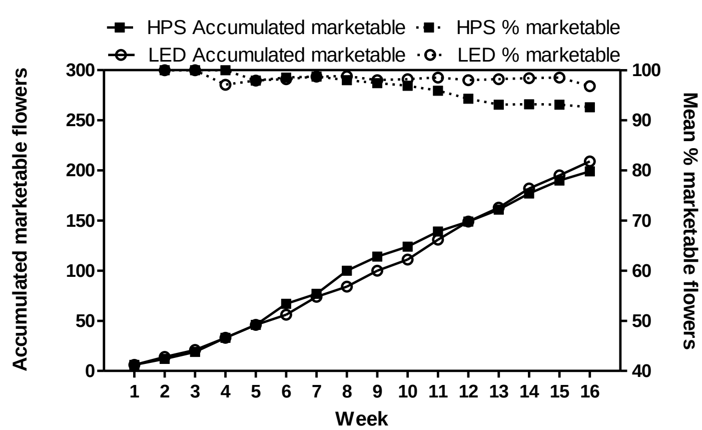
Figure 6. Flower harvest metrics for the 6 cultivar x lighting system treatment combinations.

Numbers of accumulated flowers harvested, as well as percent of marketable flowers were also analyzed (Figure 7). Percent (%) marketability is calculated as the ratio of marketable flowers to total flowers harvested. From a commercial production standpoint, this data may be of greatest interest to the growers. Note that there were substantial differences in both total accumulated numbers of flowers harvested and % marketable flowers for the 3 cultivars. In particular, when comparing the two standard flower cultivars, Acapulco produced about 25% more marketable flowers over the trial than Heatwave, and had consistently high % marketability. From a production standpoint, Heatwave would appear to be a much better choice in terms of consistently and total flower production. Note that, in general, crops grown under HPS performed as well or better than under LED during the early part of the supplemental lighting season. However, during the latter part of the season, crops grown under LED surpassed the HPS grown crops and by the end of the trial all three cultivars produced greater numbers of marketable flowers as well as had higher % marketability (thus higher total numbers of flowers harvested) under LED.

Heatwave



Acapulco



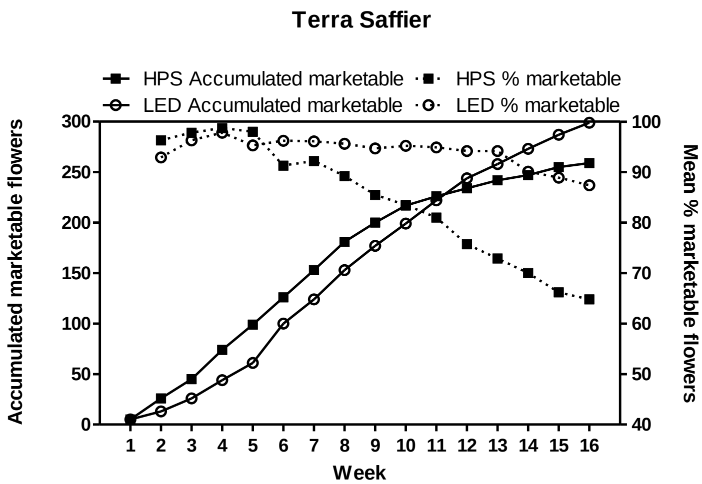


Figure 7. (See previous page.) Total Accumulated harvest and % marketable for the three cultivars and two supplemental lighting treatments during the 16-week supplemental lighting trial. Note that harvest numbers are the sum of flowers harvested from 56 plants, for each cultivar X supplemental lighting treatment combination.

Figure 8 shows accumulated per-plant flower harvest data, combined across the three cultivars, for total flowers (marketable + unmarketable) as well as % marketability for the different lighting treatments. While the HPS treatment consistently produced slightly higher total numbers of flowers over the 16-week trial, there was a steady decline in the % marketability as the season progressed. In contrast the LED treatment showed relatively consistent % marketability, resulting in substantially higher per-plant marketable flowers but the end of the trial (data not shown). Note that the per-plant harvest numbers (approximately 9 flowers over 16 weeks) is somewhat lower than commercial production where growers expect > 1 flower per

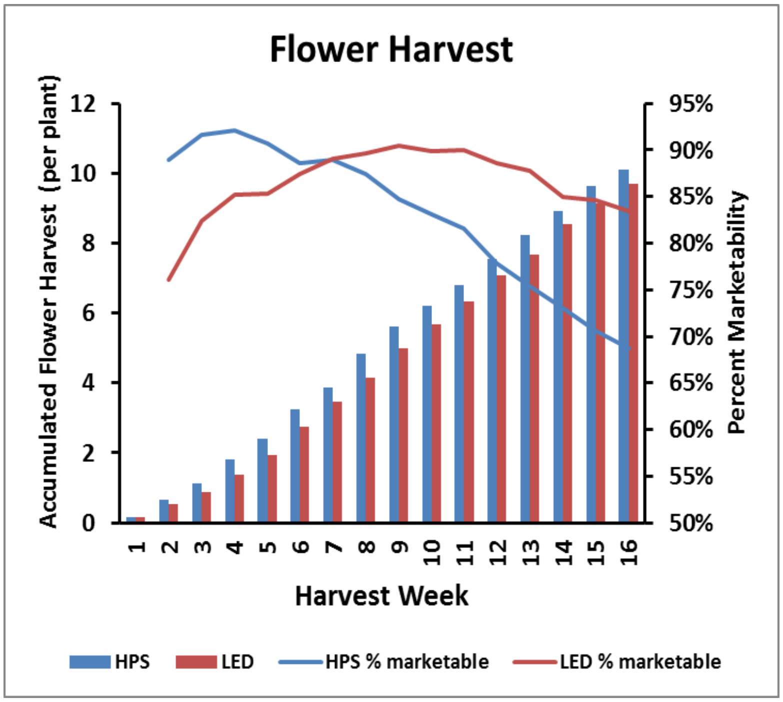


Figure 8 Mean per-plant accumulated flower harvest and percent marketability during the 16-week supplemental lighting trial.

plant per week (personal communication, Rosa Flora). This reduction is most likely due to lower ambient light levels inherent to these trials, caused by the additional infrastructure above the plant canopy to block light spillover from adjacent benches. Therefore, while the bench level PAR from supplemental lights was similar to commercial production, the total DLI was lower than in a commercial production system. In summary, the LED treatment produced 4% fewer total flowers than HPS (815 vs. 850) but 16% more marketable flowers (680 vs. 584).

Also interesting to note is the differences in total harvest # and % marketability between the lighting treatments, according to bench position. The benches closest to the south facing wall had ~25% higher recorded DLI than the other benches due to direct exposure to the sun. The DLI at the other benches were all quite similar but gradually reduced as they got farther away from the south facing wall. If one looks only at the darkest benches (ie. farthest from the south wall), where the supplemental lights contributed the largest portion of the total DLI (ie. highest supplemental : natural), the differences in flower harvest between the lighting treatments is substantial (Figure 9). All three cultivars show the same trend, so they have been grouped together in this graph. Note how the harvest of marketable flowers under HPS (blue line) practically halts after week 9. This may be evidence that the plants adapted to the LED lights during the course of the trial, resulting in greater production of high quality flowers. This is not definitive, as there could also have been another unidentified systematic factor (eg. waterborne disease) present on the HPS bench, that is unaccounted for in the harvest number analysis.

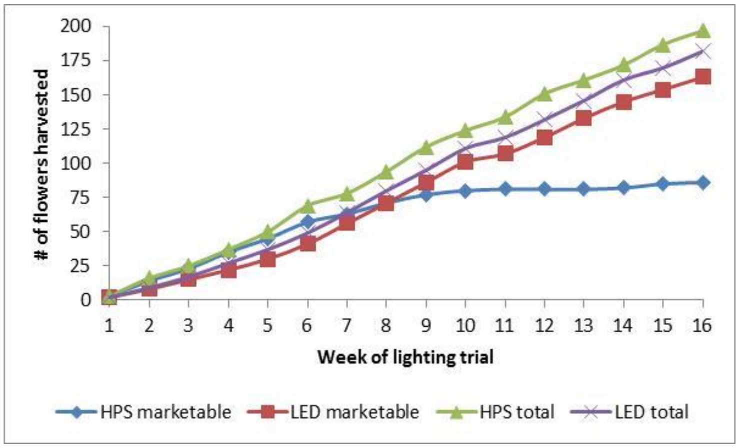


Figure 9. Total and marketable flower harvest for both lighting treatments on the benches with the highest supplemental : natural light (ie. farthest away from the south facing wall of the greenhouse).

Vase-life

Vase-life trials were performed by collecting one harvestable flower from each cultivar on each bench during flower harvests. Heels were removed from the stems by making a lateral cut 2 cm from the bottom of the stem, after which the stems were placed in sterilized graduated cylinders containing 100 mL of deionized water. The vase-life trials (Fig 10) occurred inside a windowless room that was lit constantly with fluorescent lights and maintained at an average temperature of 23.0 °C and an average relative humidity of 18.6%.

Figure 10. Experimental setup of vase life trials in a constantly lit, windowless room. Note that not all of the flowers were harvested on the same day (hence the empty graduated cylinders), so the vase life trials were staggered according to when harvested flowers were available from each bench x cultivar combination.

Flowers were considered to have reached the end of their valuable life when any of the following symptoms developed: petal wilting (flaccid petals), petal abscission, petal discoloration, and/or development of a bent neck (90^o bend at the peduncle region). Flowers were evaluated daily for the onset of any one of the above symptoms. In addition, water volumes were measured after seven days. These data were then used to compare water usage between the flowers from each treatment.

Figures 11 and 12 show the results of the vase life trials for the 6 cultivar X lighting system treatment combinations. Again, while the error bars indicate the level of variability of the means, non-overlapping bars are not necessarily an indication of statistical significance. In fact the only statistically significant lighting treatment effect was on vase life for the Acapulco cultivar, where the LED treatment extended the vase life by about 18% or 2.5 days. Note that Heatwave, the cultivar with the lowest total harvest and % marketability also had the shortest vase life and the highest water use, regardless of lighting treatment. This may be an indication of an unknown systematic (eg. disease) problem with this cultivar. Also note that Terra Saffier had the lowest water consumption of the first 7 days of the vase life trial. This result was expected since this miniature cultivar which had substantially smaller flowers (hence smaller surface area for transpiration) than the other varieties.

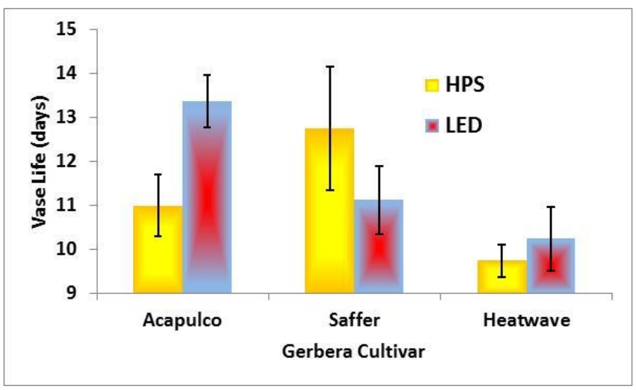


Figure 11. Vase life of the three gerbera cultivars growing under HPS and LED supplemental lighting treatments.

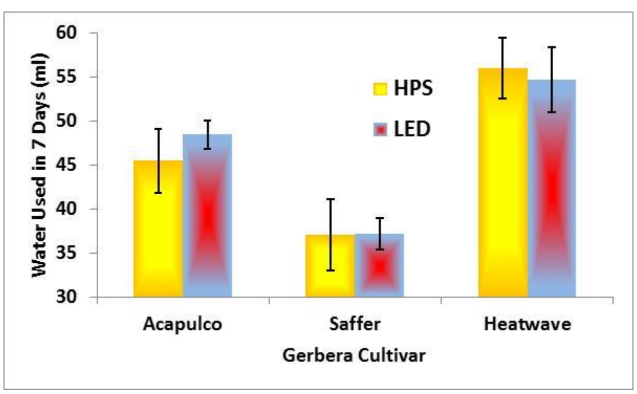


Figure 12. Water consumption in the first 7 days of the vase life trials.

Photosynthetic efficiency

Two trials were performed in order to evaluate the influence the different supplemental lighting systems had on plant biochemistry, specifically photosynthetic efficiency and CO_2 assimilation rates. Both trials utilized the LiCOR XT6400 portable photosynthesis system (Fig. 12), which uses an array of infrared gas analysers and other high precision environmental sensors to monitor leaf-level photosynthesis and gas exchange.

Figure 13. LiCOR XT6400 portable photosynthesis system.

The first trial was designed to investigate the photosynthetic efficiency of the gerbera plants (Terra Saffier cultivar only) grown under (GU) and measured under (MU) the four different combinations of supplemental lighting treatments: 1) GU HPS/MU HPS, 2) GU LED/MU HPS, 3) GU HPS/MU LED, 4) GU LED/MU LED. Three plants from each bench (12 per treatment) were randomly selected and the photosynthetic rates were measured on the last fully expanded leaf, under both supplemental lighting systems, at night, with leaf-level PAR intensities of 70 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The results (Fig 14) indicated that, regardless of the light source that the plants were tested under, the plants grown under LED supplemental lighting had substantially higher (~20%) photosynthetic rates than the plants grown under HPS supplemental lighting.

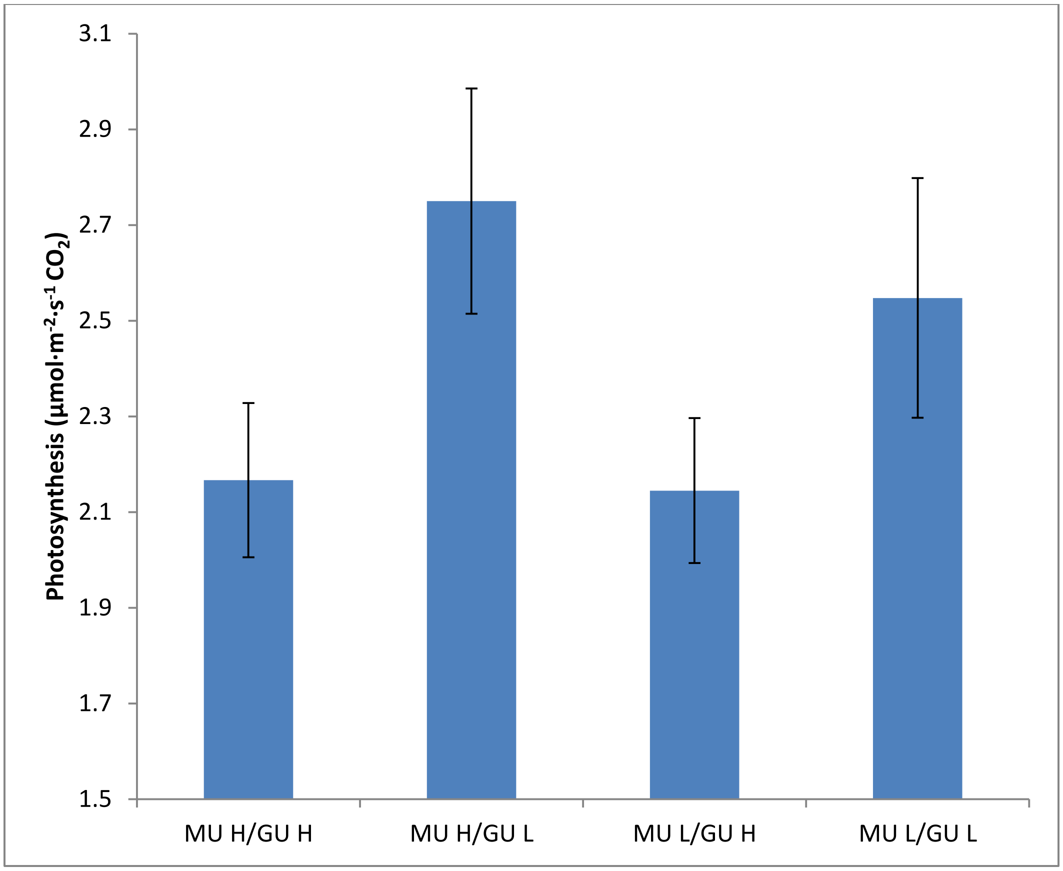


Figure 14. Photosynthetic efficiency of Terra Saffier cultivar measured under (MU) and grown under (GU) both HPS and LED lighting systems.

To further investigate the relationship between supplemental lighting treatment and photosynthetic efficiency, a second, more intensive trial was performed which generated light and CO_2 reponse curves for the same plants tested in the first trial. The light curves were measured under 400 ppm CO_2 and the CO_2 curves were measured under 1300 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR. The results showed that plants grown under both supplemental lighting systems became 'light saturated' (the point where additional increase in PAR does not result in an increase in photosynthetic rate) at about 800 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (Fig 15). However, the photosynthetic rates of the plants grown under LED had substantially higher photosynthetic efficiencies than the plants grown under HPS.

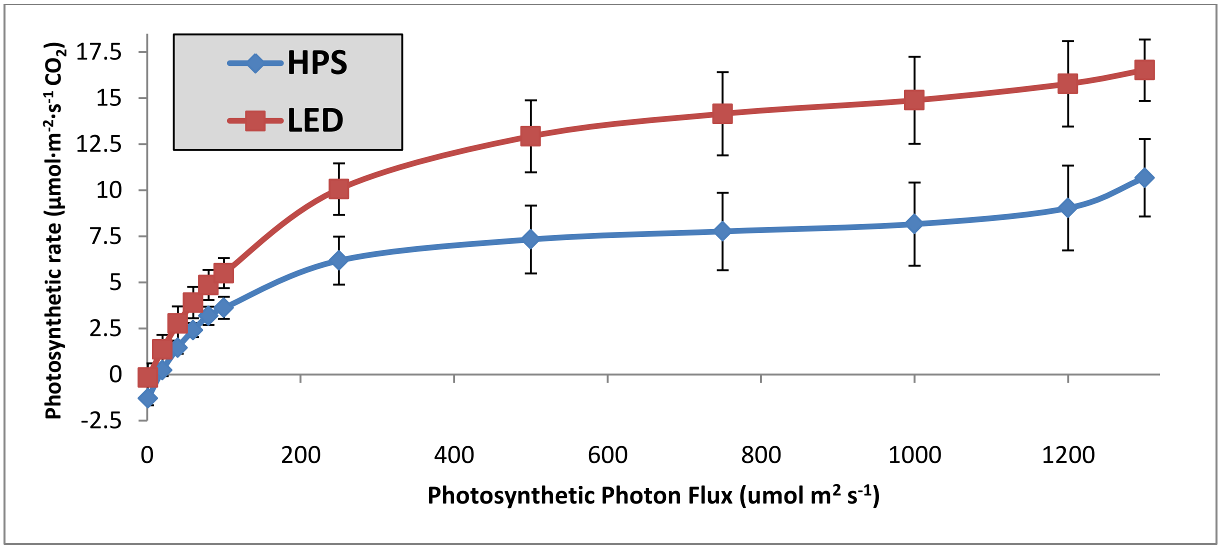


Figure 15 Light curves for gerbera (Terra Saffier cultivar) grown under HPS and LED supplemental lighting

One potential possibility for the higher photosynthetic efficiency for the LED treatment was a change in leaf morphology. To determine if leaf morphology played a role, leaf specific surface area (ie. leaf area/dry weight) was determined by destructively sampling last fully matured leaves from 12 plants of each cultivar. Areas were measured with a LiCOR leaf area meter and then leaves were placed in a drying oven at 60 °C for 48h and subsequently weighed. Figure 16 shows that there were no real influences between the two lighting treatments on leaf morphology for all three cultivars.

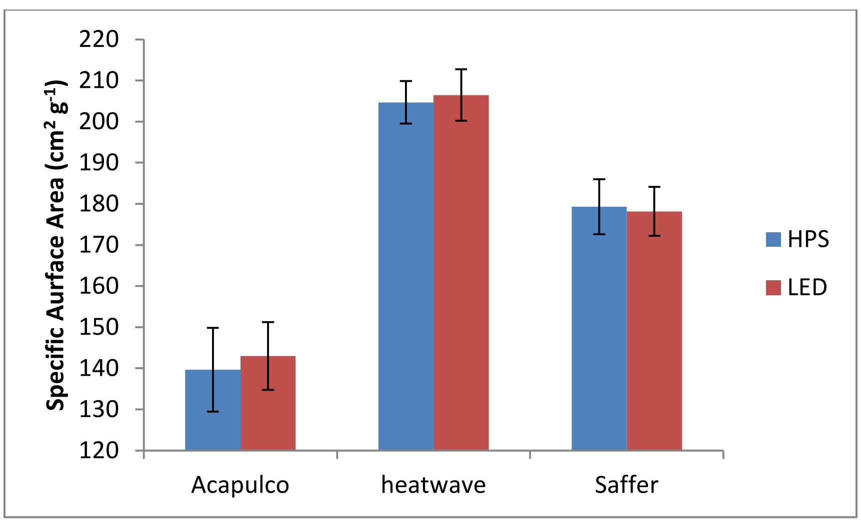


Figure 16. Leaf Specific Surface Area for 3 cultivars of cut gerbera grown under HPS and LED supplemental lighting.

These results generate more questions than answers. Clearly, the LED supplemental lighting treatment increased the photosynthetic efficiency of the plants. This did not necessarily directly translate into increased production metrics for the cut flowers.. However, the LED treatment did produce 16% more marketable flowers (ie. higher quality). More work is clearly needed to determine the mechanisms for increased photosynthetic efficiency and production implications of using LED supplemental lights for growing cut gerbera.

Wrap-up

This project progressed very well with excellent collaboration between the researchers and our commercial partners both at Lumigrow and Rosa Flora. Tech transfer has been ongoing with regular update teleconferences and internal progress reports between the collaborators. Additionally, an audience-appropriate poster was recently developed and presented at Cultivate2014, in Columbus Ohio. Travel to the conference was paid in full by Lumigrow, in addition to their prescribed financial commitments to the project. We are currently finalizing a scientific manuscript, describing the results of this project, which will be submitted shortly to Hortscience for publication.

The project, as a whole, proceeded extremely well and was completed both on time and within budget. There has been a high level of satisfaction with the quality of the research and the results have been both of great value to the lighting manufacturer, Lumigrow, and commercially relevant to the cut flower industry. While LED lighting technology has seen remarkable growth in the horticulture industry, especially in the last decade, this is the first study of its kind that has investigated in detail the use of LED technology as supplemental assimilation lighting for the production of cut flowers. The results have shown that commercially available LED technologies have matured to a level where they can compete favorably with traditional HID lighting technologies for supplemental lighting applications in greenhouse floriculture.

Next Steps

Lumigrow's LED technology has clearly shown its potential for use in the cut flower industry, especially in northern climates where there is not enough natural light to effectively grow high value cut flowers, such as gerberas, during the darker months of the year.

There has been a strong desire to continue with our research partnership with Lumigrow and the International Cut Flower Growers Association. There are a lot of potential questions to be answered with respect to utilizing commercially available LED lighting technologies for supplemental assimilation lighting in the floriculture industry. After conferring with industry representatives, one of the most pressing questions is: what is the optimum level (ie. crop level PAR) of supplemental LED lighting for growing cut flowers, especially during the darker months in northern climates? We have already developed a proposal, aimed at gaining further insight into this question during the 2014/2015 supplemental lighting season.

Acknowledgements

We thank the International Cut Flower Growers Association and the Joseph H. Hill Memorial Foundation, Inc. for the generous financial support. We also thank LumiGrow and Rosa Flora for their in-kind contributions, and technical support during this study.