Exposure with Far-red Radiation for Control of Oedema Injury on 'Yale' Ivy Geranium

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Abstract. Oedema, a physiological disorder, affects several cultivars of ivy geranium [*Pelargonium peltatum* (L.) L 'Hér. ex Ait) when grown in greenhouses. This study investigated the regulation of oedema on this crop using far-red radiation because these wavelengths inhibited the injury on *Solanaceous* sp. Plants were exposed to far-red radiation from Sylvania #232 far-red lamps on abaxial and adaxial surfaces of leaves. A far-red photon flux of 15 to 20 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (700-800 nm) was not effective in preventing oedema injury. A far-red abaxial treatment during the light period tended to reduce the amount of injury that developed when photosynthetic photon flux was low (130-170 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$), but this inhibition of the injury was absent with higher photon flux. The results from these studies indicate the use of supplemental far-red radiation treatments in greenhouses would not be justified because adequate and consistent control of the injury on ivy geraniums was not achieved.

Throughout its cultivated history, *Pelargonium peltatum* has been affected by the physiological disorder oedema, or intumescence injury. This disorder is described as physiological because no pathogens are associated with injury. Injury is generally visible as 1- to 3-mm blisters or galls on lower surfaces of recently matured leaves. As severely affected leaves age, they may become chlorotic and necrotic, and abscise. Death of leaf tissue decreases aesthetic and economic value of this crop.

The predominant explanation for injury has been that it occurs under conditions of high relative humidity (RH), high soil moisture, and cool weather, which lead to an excess of water in leaf tissues and gall development (Metwally et al., 1971). Recent work investigating intumescence injury on *Solanaceous* sp. found that the disorder is controlled by the phytochrome system (Morrow and Tibbitts, 1988). Red radiation (600-700 nm) was required for injury to occur, and far-red radiation (700-800 nm) prevented injury development. Based on this report, the following experiments were undertaken to establish whether use of a supplementary far-red radiation treat-

ment in the growing environment would protect ivy geraniums from oedema.

A far-red exposure was applied to the abaxial side of leaves in most studies because injury develops primarily on this surface of ivy geranium leaves (Balge et al., 1969). This exposure method allowed for treatment of separate plants with different far-red levels within a single growth chamber. For undersurface exposures, lamp boxes were constructed of opaque gray polyvinyl chloride with no top or bottom. These boxes housed lamp fixtures for far-red radiation treatments and were covered with a sheet of transparent acrylic plastic that absorbed ultraviolet (UV) radiation emitted by lamps. Ultraviolet radiation has been shown to inhibit oedema injury on other species (Morrow and Tibbitts, 1988). Control plants did not receive supplementary radiation to the lower surface of leaves.

The far-red radiation treatments were provided with 50-cm Sylvania #232 far-red fluorescent lamps. To remove emissions in the blue and red wavelengths, lamps were wrapped with colored cellophane filters. A low level of far-red photons, 2.8 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (700-800 nm), was obtained with a Roscolux #27 dark-red filter (Musson Theatrical, Santa Clara, Calif.). A high level of far-red photons, 4.3 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (700-800 nm), was obtained by wrapping lamps with a 0.4-mm-thick red acetate filter material (Trancil Wrap, North Lake, Ill.). The spectrum provided by these far-red treatment lamps (Fig. 1) was determined with a spectroradiometer (model 550/551; EG&G, Salem, Mass.).

The chamber lighting was provided by an overhead bank of cool-white fluorescent lamps. A layer of polyethylene plastic was installed immediately beneath chamber lamps to remove UV radiation emitted by them. Photosynthetic photon flux (PPF) within the chamber was measured with a LI-COR 185 quan-

tum meter (LI-COR, Lincoln, Neb.) and adjusted to the desired level by installing layers of cheesecloth below the light bank.

'Yale' ivy geranium was used because of its high susceptibility to oedema injury. Rooted cuttings were received from Olgevee Associates (Connellsville, Pa.), potted into 0.5-liter plastic pots using a 50 peat :50 vermiculite (v/v) medium, and grown at an irradiance level of 160 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPF, at 22 $\pm$ 2°C, and 70% $\pm$ 4% RH. After 3 weeks of growth, plants of similar appearance with stems >20 cm long were selected and transplanted into rectangular plastic containers, 60 $\times$ 15 $\times$ 20 cm (length, width, depth), with a 50 peat :50 vermiculite (v/v) potting medium. Two or three plants were transplanted into each container. All flowers and sideshoots were removed at transplanting and throughout the experiment, limiting growth to a single stem. As plant stems elongated, they were positioned horizontally over the selected lamp boxes for treatment and maintained using twist ties hooped over stems and secured to box covers. A modified half-strength nutrient solution (Hammer et al., 1978) was applied four times daily to excess, to each plant container using an automatic drip tube watering system. Plants were grown for 1 week after transplanting. Radiation treatments were then initiated.

The first experiment was conducted to determine if abaxial treatments with far-red radiation would prevent injury. Two plant containers with two plants in each were placed within the chamber. One plant from each container was positioned over a lamp box and received a far-red treatment of 2.8 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ for the duration of the light period and the other plant was positioned over an empty lamp box and received no abaxial radiation. The over-head cool-white PPF level, measured at the surface of the boxes, was 130 $\pm$ 15 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ for a 16-h light period. The chamber was maintained at 18 $\pm$ 2°C and 70% $\pm$ 4% RH over the light and dark period. Experiment duration was 6 weeks.

In a second experiment, two levels of far-red radiation were investigated with a chamber PPF of 165 $\pm$ 15 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, a level 27% higher than that supplied in the first experiment. Three containers, each holding three plants, were prepared for the study. One plant was positioned over a far-red photon flux of 2.8 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, the second over far-red of 4.3 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, and the third over an empty lamp box. Temperature, RH, and duration of the light period were maintained at the levels used for the first experiment. Experiment duration was 6 weeks.

A third experiment investigated the use of far-red radiation treatment at 2.8 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ with an elevated chamber PPF of 230 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. This chamber irradiance level was the highest used in the abaxial exposure studies. Three containers, each with two plants, were prepared for this study. One plant received abaxial far-red treatment and one plant received no abaxial treatment. Temperature, RH, and duration of light period were maintained at the levels used for the first experiment. Experiment duration was 6 weeks.

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Spectra of low and high far-red photon flux used in abaxial leaf irradiation studies.

The use of a far-red radiation treatment at the end of the light period was investigated in a final study. A far-red fluorescent bulb wrapped with Roscolux #27 cellophane was used to supply the treatment. A 48-cm-long fluorescent fixture was hung over plants to provide treatment to the upper surfaces of leaves. This lamp was 45 cm above plants and supplied a far-red photon flux of $4.2 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. Far-red treatment was applied for 15 min, beginning 5 min after the start of the dark period.

Plants were grown from cuttings in 0.5-liter plastic pots, as described previously. Sixteen plants were selected for the experiment based on uniformity of stem length and size of youngest leaf pair. Eight treatment plants were arranged, four on each side of the far-red fixture. Eight control plants, which received no far-red radiation, were placed next to the treatment plants, farther from the far-red source. A black cloth barrier was suspended between control plants and treated plants at the start of each dark period, so essentially no far-red radiation reached control plants. This screen was removed at the end of each dark period to minimize any temperature and light differences during the light period. Overhead PPF from cool-white fluorescent lamps was $390 \pm 8 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPF, providing a 12-h light period. No UV-absorbing barrier existed in this chamber, which was maintained at $23 \pm 3^\circ\text{C}$ and $70\% \pm 4\%$ RH. Experiment duration was 4 weeks.

In the first three experiments, plants were harvested by cutting stems at soil level. Differences in whole-plant appearances were recorded. Each node generally had two leaves, and leaf diameter was measured at the widest part of each blade. The node closest to the growing point with leaf diameters >3.0 cm was denoted as node one. Leaves from the fourth and fifth nodes were evaluated for oedema by laying a transparent grid marked with 0.25-cm^2 squares over a leaf and counting the number of grid squares containing galls. The total number of squares encompassing the leaf surface was recorded also. The percentage of squares containing oedema was then calcu-

lated, and this value reported as the percentage of leaf surface injured. Data from leaves at the fourth and fifth node were averaged to represent the amount of oedema per plant.

In the fourth study, injury evaluation was modified to decrease time for counting galls. Extent of oedema injury was recorded by counting the number of galls in a 6.5-cm^2 area centered over the point of petiole attachment. Ivy geraniums develop injury predominately around the point of petiole attachment. In later stages of injury, galls develop in distal regions of leaves, but these galls are smaller and less distinct than those near the petiole. The four oldest leaves on each plant that developed during treatment were evaluated in this experiment, and the number of galls averaged to obtain an average injury per plant. Leaf areas were recorded for these scored leaves. Internode lengths between leaves initiated during the experiment were recorded also. Data from these paired samples were compared using Student's *t* distribution.

Far-red treatments during the light period (Expts. 1-3) were not effective in preventing gall formation (Table 1). With PPF of 130 and $165 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, there was some reduction in gall formation relative to the control, but differences were not significant. No reduction in oedema occurred with the highest level of far-red.

Far-red treatments during the light period tended to induce leaves to grow larger, although not significantly so, than those on plants receiving no abaxial far-red exposure (Table 2). Although such differences were not statistically significant in anyone experiment, there was an increase in area with far-red treatments in all experiments. Some internodes were observed to be elongated; however, lengths were not recorded.

Treatment with far-red photons for 15 min at the start of the dark period increased, rather than decreased, the level of oedema that developed on plants (Table 3). This far-red treatment, when applied at the beginning of the dark period, doubled the number of galls on evaluated leaves. Internodes of plants receiving end-of-day treatments were elongated, averaging 11.7 cm, compared to controls, which averaged 7.7 cm. Leaf areas were slightly larger in far-red-treated plants than in control plants (Table 3).

The effect of supplemental far-red treatments appeared to interact with chamber PPF, although the individual or interacting effects were not significant. Under PPF $<170 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, addition of far-red photons appeared to cause some decrease in oedema formation. Stems elongated more in treated than in control plants, although lengths were not recorded. Stem elongation is known to result from enhanced far-red flux on many species (Holmes and Smith, 1977), indicating that plants perceived supplemental far-red treatments. However, when chamber PPF exceeded $170 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, far-red treatment had no effect on treated plants, and no difference in stem elongation was observed in our experi-

Table 1. Effect of far-red photon flux (700–800 nm) during the light period on oedema injury of plants grown at three photosynthetic photon flux levels.

Far-red flux ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)	Photosynthetic photon flux ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)		
	130	165	230
	Leaf area injured (%) ^f		
0	8.6 ± 5.3	49.3 ± 15.1	15.7 ± 8.9
2.8	$3.8 \pm 3.4^{\text{ns}}$	$31.6 \pm 7.1^{\text{ns}}$	---
4.3	---	$34.3 \pm 16.3^{\text{ns}}$	---

^zAverage $\pm$ sd of eight leaves for plants at $130 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and of 12 leaves for plants at 165 and $230 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$.

^{ns}Leaf area injured not significantly different from control plants at $P \leq 0.05$.

Table 2. Effect of far-red photon flux (700–800 nm) during the light period on leaf area of plants grown at three photosynthetic photon flux levels.

Far-red flux ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)	Photosynthetic photon flux ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)		
	130	165	230
	Leaf area ^a (cm^2)		
0	68.7 ± 11.4	53.1 ± 7.6	74.9 ± 7.2
2.8	$76.6 \pm 7.6^{\text{ns}}$	$75.8 \pm 9.4^{\text{ns}}$	$78.3 \pm 4.6^{\text{ns}}$
4.3		$65.8 \pm 3.1^{\text{ns}}$	

^zAverage $\pm$ sd of eight leaves for plants at $130 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and of 12 leaves for plants at 165 and $230 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$.

^{ns}Leaf area not significantly different from control plants at $P \leq 0.05$.

Table 3. Effect of far-red photon flux ($4.2 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) supplied for 15 min at the beginning of the dark period on plant growth and oedema injury.

Variable	Far-red	No far-red
Leaf area (cm^2) ^z	$73.4 \pm 7.0^*$	60.1 ± 8.7
Internode length (cm) ^y	$11.7 \pm 1.7^*$	7.7 ± 0.6
Number of galls ^x	$37.6 \pm 17.0^*$	18.5 ± 6.8

^zAverage of the four oldest leaves of eight plants $\pm$ SD.

^yAverage length of three internodes of eight plants $\pm$ SD.

^xNumber of galls for 6.5-cm^2 area of leaf at point of petiole attachment.

*Significantly different from control plants at $P \leq 0.05$.

ments. The far-red effects may have been masked by increased red wavelengths under higher chamber PPF. This result suggests that a particular proportion of far-red to red photon flux reduces the level of oedema, and a far-red level below a critical proportion has no effect on injury. Additional research is necessary to determine if a higher far-red: red photon flux ratio may inhibit injury. However, higher far-red flux may induce excessive stem elongation and make treatment valueless.

The plants treated with far-red at the start of the dark period showed increased stem elongation and double the level of injury compared to the control plants. The elongation may be attributed to the far-red treatment; however, the cause of the elevated level of injury is unknown.

The control of oedema by far-red treatment of ivy geraniums was much less than the con-

trol found on *Solanaceous* sp. In our studies, no treatment reduced gall formation more than 50%, whereas on *Solanaceous* sp., intumescence injury was inhibited with far-red exposure (Morrow and Tibbitts, 1988). Thus, we conclude that oedema injury has different causal factors on geraniums than on *Solanaceous* sp. and is regulated by different physiological systems within the separate species of plants. This difference is supported by the fact that UV radiation appears to have little effect on oedema in geraniums, yet effectively prevents injury on *Solanaceous* sp. (Morrow and Tibbitts, 1988). This lack of UV regulation on geraniums was apparent in the fourth experiment, where oedema developed on all plants, even though plants were being irradiated with UV wavelengths from the unfiltered cool-white fluorescent lamps. *Solanaceous* plants, grown under similar levels of UV wavelengths from cool-white fluorescent lamps, did not develop oedema (Morrow and Tibbitts, 1988). The possibility that oedema on geraniums has different casual factors than on *Solanaceous* plants also is indicated by the observation that the symptoms on geraniums develop primarily on mature, fully enlarged leaves, whereas oedema develop primarily on enlarging leaves of *Solanaceous* sp.

From the results of these experiments, we conclude that installing far-red treatment systems to control oedema on ivy geraniums in a commercial facility would not be beneficial. The plants would need to be treated from the time of planting to the time of sale, and the injury still may not be completely inhibited.

Indication of control appeared probable under low PPF levels; however, in greenhouses where solar PPF fluctuates with season and cloud cover, maintenance of a useful level of far-red flux would be difficult. Also, greenhouse PPF levels generally are higher than those used in the experiments; therefore, applying an adequate amount of far-red flux may induce undesirable stem elongation. Thus, the primary consideration for growers plagued by oedema injury should be selection of cultivars that are resistant to injury and careful management of the production environment to avoid excess watering, high humidity, and high light intensity.

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