Acceleration of *Begonia* $\times$ *semperflorens-cultorum* Growth Using Supplemental Irradiance

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Abstract. Plug flats of *Begonia* $\times$ *semperflorens-cultorum* Hort. 'Pizzazz Red', 'Vodka', and 'Viva' were provided 0, 50, 125, or 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ metal-halide supplemental irradiance in the greenhouse for 0, 2, 4, 6, or 8 weeks. Treatments were initiated when seedlings were in the first true leaf stage (2 weeks after sowing). Plug-grown begonias reached transplantable dry weight and leaf area after 4 weeks of 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental exposure, while those under 0 and 50 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ required 6 to 8 weeks. Fewest number of days to visible bud and anthesis and the fewest number of nodes for all cultivars occurred after 2 weeks of 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental exposure. The same conditions achieved the greatest final leaf area and plant height; however, final dry weight was unaffected. Additional supplemental irradiance and/or exposure time did not accelerate flowering or improve vegetative growth of finished plants.

Bedding plants are sown primarily in the winter months for spring sales. Light levels during the winter may limit growth. Considerable research has been undertaken to reduce the interval to crop harvest with high-intensity supplemental irradiance in the greenhouse. High-output lamps applied as a supplement to ambient light for 4 to 6 weeks was successfully used during the winter on hybrid seed geranium (*Pelargonium* $\times$ *hortorum* Bailey) to reduce the number of days from sowing to flowering (Armitage and Tsujita, 1979a; Armitage et al., 1978; Tsujita, 1982). Bethke (1986) found that a threshold supplemental irradiance level of 45 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ was needed to reduce the number of days from sowing to anthesis and node number in seed geranium. Total plant height, number of lateral breaks, and fresh weight were positively correlated to cumulative photosynthetically active radiation (Erickson et al., 1980). Dry weight, leaf area, leaf thickness, specific leaf weight, and net photosynthetic rate increased as quantum flux density increased (Armitage et al., 1983). Graper and Healy (1987) found that when 120 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ sodium vapor light was applied to begonias after 10 to 15 or 10 to 20 days from sowing, seedling dry weight increased and number of days to flower decreased.

Although applying high-intensity supplemental irradiance in the greenhouse reduced the number of days to flowering in wax begonia (Graper and Healy, 1987), data on the effects of the combination of irradiance intensity and duration of exposure for optimization of growth of begonia seedlings in plug flats are lacking. In addition, cultivar response has not been determined. These data would help growers finish begonia plugs more quickly and would likely reduce the cost of production. The purpose of this study was to investigate the effects of intensity and duration of high-intensity supplemental irradiance on growth of young begonia seedlings in plug flats and ascertain carry-over effects on mature plants.

Seeds of *Begonia* $\times$ *semperflorens-cultorum* 'Pizzazz Red', 'Vodka', and 'Viva' were sown in 288-cell plug flats (0.006 cm^3/cell) (Park Seed Co., Greenwood, S. C.) on 14 Jan. 1988. On 1 Feb. 1988, seedlings were transported to Athens, Ga., for treatments. One plug flat of each cultivar was placed in a glass greenhouse under 0, 50, 125, or 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance provided by metal-halide lamps (400 W, 240 V) for 16 h-day⁻¹. Treatments were separated on the bench by black plastic curtains to prevent light leakage. Ambient light treatments received seasonal light levels and photoperiods only. Night temperature was 18 $\pm$ 3C and day temperature varied with ambient but did not exceed 29 $\pm$ 3C. Day air temperature under 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance was 2 to 3C higher than at other light levels. Seedlings were fertilized with 75 mg N/liter from KNO₃ (13.8N-0P-44.5K) at each irrigation and leached once a week with tap water to reduce soluble salt buildup.

At the end of 2, 4, 6, or 8 weeks of supplemental irradiance exposure or upon

reaching transplant size, seedlings of each cultivar were removed from irradiance treatments to ambient conditions. In general, transplant size was reached when leaves of seedlings in a plug flat contacted those of adjacent seedlings and, on average, consisted of 3 mg of dry weight and a leaf area of 1.4 cm^2 . Upon reaching transplant size, nine seedlings from each treatment were transplanted to 18-section cell packs (336 cm^3/cell) containing soilless medium [3 pine bark : 2 sphagnum peat : 1 perlite : 1 vermiculite (by volume)]. Transplants were fertilized at each irrigation with 125 mg N/liter from 15N-7.1P-14.1K and leached once a week with tap water to reduce soluble salt buildup. Leaf areas and dry weights from nine seedlings were recorded at the end of a treatment period or upon reaching transplant size. Date of the first visible bud was recorded when the terminal staminate flower bud was 0.5 cm wide. Plant height (measured from the container rim to the shoot apex), leaf area, and node number (number of nodal positions from the first mature leaf to the first inflorescence) were recorded at visible bud. Treatments were analyzed as a completely randomized design using linear regression analysis. Comparisons of regression equations were performed using *t* tests. All tests of significant differences were at *P* = 0.05.

Analysis of variance results indicated a significant cultivar $\times$ irradiance $\times$ time interaction for seedling leaf areas and dry weights. Leaf areas and dry weights of seedlings increased over time, but the greatest increase in these quantities occurred when

Fig. 1. Effect of 0 (○), 50 (△), 125 (●), or 200 (▲) $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance on seedling leaf area of (A) 'Pizzazz Red', (B) 'Vodka', and (C) 'Viva' begonias. Transplant leaf area (TLA) = 1.4 cm^2 .

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Fig. 2. Effect of 0 (○), 50 (△), 125 (●), or 200 (▲) $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance on seedling dry weight of (A) 'Pizzazz Red', (B) 'Vodka', and (C) 'Viva' begonias. Transplantable dry weight (TW) = 3 mg.

seedlings received 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance, regardless of cultivar (Figs. 1 and 2). Regression analysis indicated quadratic increases in dry weights for the three cultivars at each irradiance level over time, except for 'Vodka' when exposed to 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance. Leaf areas increased quadratically when seedlings received 125 and 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance and was linear with 0 and 50 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$. Leaf areas and dry weights did not differ between the 0- and 50- $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ exposure levels for any cultivar. Slopes for dry weights and leaf areas were significantly different in the first-order terms with 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance when compared with the 0- and 50- $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ exposure levels, while 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ resulted in the largest dry weight and leaf area gain over time.

A transplantable leaf area (TLA) of 1.4 cm^2 was reached by 'Vodka' and 'Viva' after 4 weeks of treatment (6 weeks from sowing) with 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance (Fig. 1 B and C). All cultivars reached transplant size by 6 weeks regardless of light level, except 'Pizzazz Red' when given 0 and 50 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance (Fig. 1A). Leaf areas increased with 0, 50, and 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance between 6 and 8 weeks, but was suppressed when exposed to 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, regardless of cultivar (Fig. 1). All cultivars, except 'Pizzazz Red', reached a transplant dry weight (TW) of 3 mg after 4 weeks of 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance (Fig. 2). Only 'Viva' reached a trans-

Fig. 3. Effect of 50 (△), 125 (●), or 200 (○) $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance on days from sowing to visible bud for (A) 'Pizzazz Red', (B) 'Vodka', and (C) 'Viva' begonias.

plantable dry weight after 4 weeks of 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance (Fig. 2C); while 'Pizzazz Red' and 'Vodka' required about a 5-week exposure to 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ (Fig. 2 A and B). Seedlings given 0 and 50 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance required ≈ 6 weeks to reach transplantable dry weight, regardless of cultivar.

Comparisons of regression equations for days to visible bud showed no difference between plants exposed to 50 or 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance, while those receiving 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ exposure were significantly different from the former two (Fig. 3). The number of days from sowing to anthesis for the three cultivars showed trends similar to those for days to visible bud (data not shown). The number of days from sowing to visible bud for all cultivars was accelerated when seedlings received 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance for 2, 4, or 6 weeks, except 'Viva' after 6 weeks. 'Pizzazz Red', 'Vodka', and 'Viva' required an average of 93, 93, and 101 days, respectively, to reach visible bud after seedlings received 2 weeks at 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance, while 102, 107, and 114 days, respectively, were required for those under ambient conditions. No differences in days from visible bud to anthesis were found for any cultivar (data not shown).

The fewest number of nodes to the first inflorescence for all cultivars occurred when seedlings received 2 weeks of 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance (Fig. 4). Comparisons of equations for 'Vodka' and 'Viva' for node number showed no difference

Fig. 4. Effect of 50 (△), 125 (●), or 200 (○) $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance on node number for (A) 'Pizzazz Red', (B) 'Vodka', and (C) 'Viva' begonias.

when seedlings received 50 and 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance (Fig. 4 B and C), while 'Pizzazz Red' seedlings receiving these same two light levels were different (Fig. 4A). Node number at the 125- $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ exposure level was significantly different from those receiving 50 and 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ for all cultivars (Fig. 4).

Final plant leaf area for all cultivars was greatest when seedlings received 4 weeks of 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance (Fig. 5). No significant differences were found between seedlings receiving 125 and 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance for any cultivar; leaf area with 50 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ was significantly smaller than that for the former two. Lateral bud leaf areas for the three cultivars showed trends similar to total leaf area (data not shown).

Final plant heights for 'Pizzazz Red' and 'Viva' were greatest when seedlings received 2 weeks of 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance (Fig. 6). Comparisons of quadratic equations showed no significant differences in plant height resulted from exposure to supplemental irradiance for 'Vodka' (Fig. 6B). 'Pizzazz Red' showed no differences in plant height between plants exposed to 125 and 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance, but plants receiving 50 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ were different from the former two (Fig. 6A). 'Viva' showed differences in plant heights at all three supplemental irradiance levels. No significant difference was found for final shoot dry weights (data not shown).

Transplantable seedling size is a newly defined concept that relies on the subjective

Fig. 5. Effect of 50 (Δ), 125 (●), or 200 (○) $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance on final leaf area for (A) 'Pizzazz Red', (B) 'Vodka', and (C) 'Viva' begonias.

judgment of researchers or growers. However, by quantifying transplantable leaf area and dry weight, an objective measure of environmental effects may be obtained. The begonia cultivars tested reached transplantable size, based on leaf area and dry weight, when provided with 4 weeks of 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance (Figs. 1 and 2). Seedlings receiving 0 or 50 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ of exposure reached transplantable size after 6 to 8 weeks of treatment, suggesting that 50 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance did not contribute sufficient irradiance to have a measurable effect on growth. Supplemental irradiance at 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ did not result in faster achievement of transplantable size. Air temperature at the 200 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ exposure level was 2 to 3°C higher than at other irradiance levels, which may have elevated respiration, resulting in less carbon gain. Additionally, there may have been insufficient nutritional levels at the 200-

Fig. 6. Effect of 50 (Δ), 125 (●), or 200 (○) $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance on final plant height for (A) 'Pizzazz Red', (B) 'Vodka', and (C) 'Viva' begonias.

$\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ exposure level compared to lower irradiances. This possibility is supported by previous work with supplemental irradiance and N level on roses (Armitage and Tsujita, 1979).

Days to visible bud and anthesis, and node number were reduced and final plant height increased when seedlings received 2 weeks supplemental irradiance at 125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ (Figs. 4 and 6). Additional supplemental irradiance and/or longer exposure times did not reduce flowering time or result in taller plants. These data are different from those found for seed geraniums and other bedding plants (Armitage et al., 1978; Carpenter, 1974). However, our results agree with those of Graper and Healy (1987), who found that when 120 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ sodium vapor irradiance was applied to begonias after 10 to 15 or 10 to 20 days for sowing, seedling dry weight increased and number of days to flower

decreased. Apparently, begonias are more responsive to a low level of supplemental irradiance for a short duration, while other bedding plants require 4 to 6 weeks of supplemental irradiance at higher levels (Armitage and Tsujita, 1979b; Armitage et al., 1978; Tsujita, 1982). Poor results using 50 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ supplemental irradiance agree with results obtained by Bethke (1986) using seed geranium.

This work offers practical benefits to commercial bedding plant producers. A relatively low supplemental irradiance level (125 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$) for a short duration (2 to 4 weeks) resulted in acceleration of seedling growth. An acceleration of seedling growth, in turn, results in a more rapid turnover of crops and efficient use of facilities.

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