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IN BEGONIA SEMPERFLORENS-CULTORUM

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Candice Ann Shoemaker

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William H. Carlson
Major professor

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IRRADIANCE AND TEMPERATURE EFFECTS ON RATES OF DEVELOPMENT AND MORPHOLOGY IN *BEGONIA SEMPERFLORENS-CULTORUM*

By

Candice Ann Shoemaker

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ABSTRACT

IRRADIANCE AND TEMPERATURE EFFECTS ON RATES OF DEVELOPMENT AND MORPHOLOGY IN *BEGONIA SEMPERFLORENS-CULTORUM*

By

Candice Ann Shoemaker

Three developmental phases were defined for *Begonia semperflorens-cultorum*: phase I - germination, phase II - germination to transplant (3 true leaves), phase III - transplant to first flower. The effects of temperature (18 to 32C), irradiance level (0 to 4.3 mol $day^{-1}m^{-2}$), and pH (4.5 to 7.5) were evaluated during phase I. Germination of 90 to 93% occurred at temperatures of 18 to 24C. At temperatures greater than 24, germination of 79 to 83% was seen. Begonia did not germinate in the dark. There was no difference in germination between seeds germinated in ambient irradiance conditions and seeds that received 24 hr supplemental irradiance (4.3 mol $day^{-1}m^{-2}$). No germination occurred at ph 4.5 and 5.0 while germination between 84 and 94% occurred within the pH range 5.5 to 7.5 when seeds were germinated on filter paper. When seeds were germinated in a peatlite medium adjusted to the various pH levels germination of 80% or greater occurred across all pH levels evaluated. Preliminary studies on the effects of the timing and duration of various photosynthetic photon flux (PPF) levels (160 to 288 μmol $m^{-2}s^{-1}$) with equal daily light integral (DLI) was studied during phase II. The timing of the irradiance treatment after emergence influenced leaf number at visible bud, lateral shoot number, flower number, plant height, dry weight, and days to first flower. PPF

influenced leaf number of the main stem, leaf area of the main stem, leaf lamina, plant height, leaf area ratio and days to first flower. Plants were taller and had more leaves at visible bud and flower when grown at the higher PPF level. Leaf area of the main stem leaves and leaf area ratio was greater under the higher PPF level. The effects of PPF, day temperature (DT), and night temperature (NT) during phase III on vegetative and reproductive development was determined. Plant height increased less than 2 cm as PPF level was increased from 4.4 mol $day^{-1}m^{-2}$ to 12.15 mol $day^{-1}m^{-2}$. DT and NT influenced plant height, but as with PPF, the treatment differences were only 1 to 2 cm. Average daily temperature (ADT) and the difference between the DT and NT (DIF) did not affect plant height. Primary lateral shoot number increased as temperature and PPF increased. Plants grown with supplemental irradiance (12.15 mol $day^{-1}m^{-2}$) reached visible bud ca. 7 days faster, and first flower ca. 6 days faster than plants grown under shade (4.4 mol $day^{-1}m^{-2}$). Days to visible bud and days to first flower were a function of NT and PPF. Rate of bud development was also a function of NT and PPF. Bud development rate increased as temperature increased from 14 to 26C and decreased slightly from 26 to 30C. The time from visible bud to first flower was a function of NT and PPF. As NT increased from 14 to 30C, the time from visible bud to first flower decreased from 21 days to 10 days.

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INTRODUCTION

INTRODUCTION

Begonia semperflorens Link & Otto is a native of northern Argentina and southern Brazil. It was originally introduced into Europe as a collector's plant in 1828. Even though this species was one of the earliest begonias to be discovered, its commercial value was not fully recognized until about 1870 when a cross between *B. semperflorens* and *B. schmidtiana* was made and intensive hybridization resulted in the *B. semperflorens-cultorum* group (fibrous-rooted begonia). Today *B. semperflorens-cultorum* is one of the most important plants in the bedding plant industry (number 7 in the top ten bedding plants produced in the United States).

Fibrous-rooted begonia is propagated by seed and currently 15 to 16 weeks is required for the production of marketable plants in northern latitudes. As a result the cost to the producer and consumer is high. To date, very little research has been conducted to improve cultural techniques employed for fibrous-rooted begonia production. Information regarding environmental effects on growth and development is sparse and does not provide adequate parameters for plant production. The introduction of new developments in greenhouse technology and computer-based control systems for greenhouse climate provide an opportunity to maintain an optimum environment for desired plant growth.

This study was initiated to determine the environmental effects on growth and development of *B. semperflorens-cultorum*. Three developmental phases were defined

and the effects of temperature and photosynthetic photon flux were examined for each phase.

LITERATURE REVIEW

LITERATURE REVIEW

The genus Begonia is a member of the family Begoniaceae in the order Parietales (Core, 1955; Johnson, 1931). The major characteristics common to the order include: superior ovary; stamens usually very numerous; placentas parietal and sepals imbruate (Johnson, 1931). The species *Begonia semperflorens* Link & Otto was found growing in Brazil in 1814 (Ewart, 1980). Several European hybridizers crossed it with *B. schmidtiana* around 1878, and in 1894 Benary of Germany crossed it with *B. gracilas* which led to the *B. semperflorens-cultorum* group (Ewart, 1980).

Begonias are usually classified according to their root systems as rhizomatous, tuberous, or fibrous-rooted (Irmscher, 1960; Fotsch, 1933). Although this terminology and classification should be avoided, as all begonia, in fact, have a fibrous root system, and since tubers and rhizomes botanically are stem structures, *B. semperflorens-cultorum* is classified and commonly referred to as fibrous-rooted begonia.

Begonias of the semperflorens-cultorum group are described as bushy plants with erect succulent stems. The growth habit is monopodial and indeterminate. They have glossy and smooth foliage which sometimes is sparsely hairy. The leaves are ovate to broad ovate with apices which are either rounded or obtuse. Leaves are arranged in an alternate phyllotaxy with the petiole subtended by a pair of stipules, commonly oblique at the base, successive leaves being mirror images. Color

of the leaves are green, bronzy-red, dark mahogany, and variegated (Thompson, 1976).

All begonias in this group branch readily and produce numerous basal shoots which make them full and compact plants.

All begonias are monoecious, usually bearing male (staminate) and female (pistillate) flowers in the same inflorescence (Irmscher, 1960). Core (1955) classifies the fibrous-rooted begonia as unisexual, monoecious, the staminate with two petal-like sepals, two smaller petals, and numerous stamens, the pistillate with two to five perianth parts (undifferentiated) and two to three united carpels, with an inferior ovary. Male flowers are initiated first and develop in the acropetal direction; the inflorescence usually develops with many new branches as a compound dichasium of male flowers until the inflorescence branches are terminated by easily recognizable female flowers with three-winged inferior ovaries (Peters, 1974). Inflorescences are arranged laterally in the leaf axils. After flowering has been initiated, leaves and inflorescences are usually laid down in an even proportion. The structure of the inflorescence is a dichasial or monochasial cyme, often irregular, with a mixture of mono- and dichasial branchings. Each individual flower is subtended by two more-or-less conspicuous bracts in the axils of which the inflorescence branchings occur (Peter, 1974; Berghoef and Bruinsma, 1969).

Fibrous-rooted begonia is propagated from seed, although additional plants can be obtained by taking stem cuttings from stock plants (Larson, 1980). Photosynthetic photon flux of 8-17 μmol $m^{-2}s^{-1}$ of supplemental irradiance improves seed germination (Laurie et al., 1969). No reported research was found on temperature effects on seed germination for fibrous-rooted begonia.

Begonia seedlings are transplanted as soon as the seedlings can be easily handled which is usually 8 to 10 weeks after sowing. By providing continuous supplemental lighting after germination Carpenter (1974) reported that begonia seedlings reached the transplanting stage in half the number of days normally required in the greenhouse. The seedlings which received supplemental irradiance were better branched at transplanting with larger stem diameter and leaf size. Continuing the supplemental irradiance after transplanting further improved the rate of plant development, vegetative quality and induced earlier flowering.

Graper and Healy (1987) studied the timing of supplemental irradiance after seedling emergence on seedling development of *Begonia semperflorens*. Plants treated for a five or ten day period, centering around day 10 after seedling emergence showed the greatest dry weight gain. Photosynthetic photon flux levels of 30, 70, 120, and 240 μmol $m^{-2}s^{-1}$ applied after seedling emergence were also evaluated. Increasing irradiance had a quadratic effect on increasing seedling dry weight and decreasing days to flower and transplant. The most efficient irradiance treatment utilized 120 μmol $m^{-2}s^{-1}$ for days 10 to 15 or 10 to 20 post emergence. In another reported study with *Begonia semperflorens*, Graper and Healy (1989) evaluated the effects of supplemental irradiance and soil heating on development. Root zone heating increased seedling dry weight 15% at 13 μmol $m^{-2}s^{-1}$ compared to ambient temperatures. Increasing irradiance from 13 to 233 μmol $m^{-2}s^{-1}$ increased seedling dry weight 33 and 50% when seedlings were grown at ambient and 26C respectively. The influence of supplemental heating on growth rate varied depending upon stage of development and treatment duration. A ten day supplemental heating treatment which included days 10 to 15 after germination resulted in a 20% increase

in dry weight. Treatment for five days during this period was not as effective as the ten day treatment duration.

Jeong et al., (1986) studied the effect of different light intensities (100%, 80%, 45%, 30%, and 10% of full sun light, actual light measurements were not reported) on the growth and flowering of *Begonia semperflorens*. Begonia leaf color was changed from green to red in relatively strong light intensity. Plant height, plant width, and leaf area were increased as the light intensity decreased. Under the 10% of light intensity, the plant was overgrown and showed poor flower production. It was suggested that the optimal light intensity for cultivation be 30 to 45% of natural light intensity. It was also found that when the plant was grown under lower light intensity, light compensation point and light saturation point were decreased. Net photosynthetic rate was higher when the plant was grown under the 10%, 30%, or 45% of full sun light intensities.

Plants are salable five to seven weeks after transplanting, thus cropping time for fibrous-rooted begonia is 15 to 16 weeks. Peterson and Vetanovetz (1987) studied the effects of various transplanting dates and supplemental irradiance after transplant on growth and development. Transplanted seedlings (8 weeks old) received supplemental irradiance (68 μmol $m^{-2}s^{-1}$ from 1700 to 0200) for two, four, six, or eight weeks. Plants were transplanted on February 19, March 5, and March 19. Supplemental irradiance for two weeks following transplanting decreased production time 23, 15, and 9 days respectively, for the February 19, March 5, and March 19 transplant dates as compared to plants that received no supplemental irradiance. Providing supplemental irradiance for four weeks or more reduced production time only three to five days more than two weeks of supplemental

irradiance following transplanting. Plant height increased with up to four weeks of supplemental irradiance and did not increase further if lighted six to eight weeks as compared to plants that received no supplemental irradiance.

Hershey and Merritt (1987) reported that crop productivity (CP), crop productivity efficiency (CPE), and plant form for *Begonia semperflorens-cultorum* 'Scarletta' grown under two photoperiods and compared it to other greenhouse floriculture crops. CP and CPE did not increase when the photoperiod was extended from 9 to 13 hr with incandescent lights. Stem and petiole length did increase under 13- compared to 9-hr photoperiods. Crop productivity of begonia was less than maximum values reported for some other bedding plants. However, when crop growth was expressed in terms of fresh weight rather than dry weight, begonia crop growth exceeded that reported for other bedding plants. This increased growth appeared to be due to the low dry weight to fresh weight ratio in wax begonia of 0.03.

Conclusion. Information regarding environmental effects on growth and development of *Begonia semperflorens-cultorum* is sparse. Most research reported to date has been on the effects of supplemental irradiance provided at various times from germination through anthesis on growth and development (Bickford and Dunn, 1972; Laurie et al., 1969; Carpenter, 1974; Graper and Healy, 1987; Jeong et al., 1986; Peterson and Vetanovetz, 1987; Hershey and Merritt, 1987). The effects of root zone temperature after seedling emergence has been reported (Graper and Healy, 1989) but there has been no research reports on the effects of air temperature on growth and development.

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SECTION I

Effect of Light, Temperature and pH on Seed Germination of *Begonia semperflorens-cultorum*

Candice A. Shoemaker

Department of Horticulture

Michigan State University

East Lansing, MI 48824

Abstract

Begonia semperflorens-cultorum 'Scarlanda' seeds were germinated at temperatures from 18 to 32C, with dark, a 24 hr photoperiod (continuous) or ambient greenhouse irradiance, and pH levels from 4.5 to 7.5. Germination of 90 to 93% occurred at temperatures of 18 to 24C. At temperatures greater than 24, germination of 79 to 83% was seen. Begonia seed did not germinate in the dark. There was no difference in germination between continuous and ambient irradiance conditions. No germination occurred at pH 4.5 and 5.0 while germination between 84 and 94% occurred within the pH range 5.5 to 7.5 when seeds were germinated on filter paper. When seeds were germinated in a peatlite medium adjusted to the various pH levels germination of 80% or greater occurred across all pH levels evaluated.

Introduction

Begonia semperflorens-cultorum (fibrous-rooted begonia) is propagated by seed. The seeds are extremely small, with two million seeds in a 28-gm packet (Larson, 1980). The extremely small size of the seed requires extreme care in sowing and diligent attention during germination. The seed can be carried away in a draft, adhere to the automatic seeder manifold if the humidity is too high, and get blown out of the seed flat during misting. Along with the difficulties in germination due to seed size, the long period between the first and last seeds to germinate (10 to 21 days) is also a problem. Seedlings that emerged early in the 21 day germination period can become stressed by the high humidity and temperatures and low irradiance of the germination environment. Increased popularity of fibrous-rooted begonia has stimulated the need to understand the plants physiological responses to the environment so that management of the germination and growth environment can be improved. No detailed studies of responses of fibrous-rooted begonia to temperature, irradiance, and pH during germination have been made. Current recommendations for germination are sketchy. Larson (1980) recommends that the propagation medium be very fine, the seed should be sown thinly on the surface and fine mist is helpful, because the seed will remain in place and water will not be limiting. There are no recommendations for light and the only temperature recommendation is that night temperature should be at least 18C (Larson, 1980).

The objectives of this research were to determine the effects of temperature,

irradiance and pH on seed germination of fibrous-rooted begonia.

Materials and Methods

Germination procedures for the temperature and irradiance experiments. Begonia semperflorens-cultorum 'Scarlanda' seeds were germinated in 100 x 15 mm petri dishes with two layers of Whatman filter paper moistened with 2 ml deionized water. One ml of deionized water was applied daily to keep the filter paper moistened. Fifty seeds were used per petri dish for each treatment. The treatments were replicated twice, over time, with three samples per treatment each time it was conducted.

The effect of irradiance on germination was investigated by subjecting the seeds to continuous irradiance, continuous darkness, and ambient greenhouse conditions. The continuous irradiance treatment was conducted in a reach-in controlled environment growth chamber. The continuous darkness and ambient greenhouse conditions were conducted in a controlled environment glass greenhouse. Petri dishes were covered with two layer of aluminum foil to provide continuous darkness. Photosynthetic photon flux (PPF) was 50 μmol $s^{-1}m^{-2}$ for the continuous irradiance treatment. The PPF was provided by cool-white fluorescent (GE, F48T12, CW 1500) lamps. PPF was measured with a LI-COR LI-185B meter and LI- 190SB quantum sensor. The temperature was maintained at a day and night temperature of 24C in the growth chamber and the greenhouse throughout the germination period. Actual average temperatures in the greenhouse during the experiment did

not vary by more than 1.6C from the desired temperature setpoint.

Seeds were also germinated at six constant temperatures of 18, 21, 24, 27, 29, and 32C. The temperature experiments were conducted in reach-in controlled environment growth chambers with continuous PPF of 50 μmol $s^{-1}m^{-2}$.

Germination procedures for the pH experiment. Filter paper experiment. Seeds were germinated in 100 x 15 mm petri dishes on saturated filter paper at pH 4.5 to 7.5 in 0.5 increments. One ml of buffered pH solutions [potassium phosphate (0.2 M) and calcium phosphate (0.2 M or 0.1 M)] was applied daily to maintain saturation. One hundred seeds were used per petri dish. The experiment was replicated twice, over time, with three samples per treatment per replication.

Peatlite experiment. Seeds were germinated in 100 x 15 mm petri dishes containing a 50:50 sphagnum peat/coarse vermiculite medium (peatlite). Four liter quantities of medium was adjusted to the various pH levels by adding up to 200 g calcium carbonate. After the calcium carbonate was added, the pH was monitored to determine when the reaction stabilized. The pH was determined with a 1:1 medium/distilled water mixture (by volume). After 48 hr, three consecutive pH measurements of similar readings indicated the reaction had stabilized so the experiments were initiated. Two hundred ml of medium was used per petri dish. Medium pH was within +0.2 increments of their desired level at the beginning of the experiment. The pH of each petri dish was determined at the conclusion of the experiment. Medium pH was within $\pm$0.1 unit of the desired level at the conclusion of the experiment except at target pH 5.5 medium, where actual pH was 5.9. The results from this treatment were excluded from analysis.

At the onset of the experiment, 4 ml of deionized water were applied to the medium in each petri dish. Subsequent waterings were made by using 2 ml of solution buffered at the respective pH levels. Ten seeds were placed, uncovered, in each petri dish for each species. The experiment was replicated twice, over time, with three samples per treatment per replication.

The pH experiments were conducted in reach-in controlled environment chambers with day and night temperature set points of 24C and continuous PPF of 50 μmol $s^{-1}m^{-2}$.

Preliminary studies. Observation of daily counts of germinated seeds in preliminary work indicated that germination was not delayed by pH in the range evaluated and was delayed only slightly (2 days) at 24C compared to 27 and 32C (Table 1). Germination procedures for the preliminary work was the same as just described for the temperature and pH experiments except only 10 seeds were used per replication.

The daily germination counts indicated the pattern of germination for fibrous-rooted begonia. Visible signs of germination were ca. 10 days after sowing, at which time 60 - 75% of the seed were germinated. Eighty to 90% of the seeds had germinated within an additional 4 days. These data suggest that the germination environment should be maintained for 2 weeks instead of 3 weeks, which is currently recommended (Larson, 1980). However, for the experiments reported here, current germination recommendations were followed, thus the germination environment was maintained for 21 days.

Since rate of germination was not affected by pH from 4.5 to 7.5 or

temperatures of 24 to 32C, number of seeds germinated was recorded 21 days after sowing for all experiments reported here. Data were transformed using arcsin transformation and then subjected to analysis of variance and trend analysis. Since no seed germinated at pH 4.5 and 5.0 in the filter paper experiment, data from these treatments were excluded from trend analysis to remove bias. A t-test was conducted to compare means between continuous and ambient irradiance treatments.

Results and Discussion

Temperature. Ninety to 93% of the seeds germinated at temperatures of 18 to 24C while percentage germination at temperatures of 27 to 32C was 79 to 83% (Table 2). Germination at all temperatures evaluated was higher than the percentage germination indicated by the seed supplier (75%, Ball Seed Co.). In general, final percentage germination decreased linearly with temperature over the range of 18 to 30C (Table 2). This response is similar to Milthorpe and Moorby's (1979) report that the highest germination is often obtained at the lowest temperatures at which the seeds will germinate and germination decreases slightly with increase in temperature up to about the optimum and more rapidly thereafter.

No minimum or optimum temperature can be determined from this research, although this data shows that, on the average, 80 to 90% of the seeds will geminate within the temperature range evaluated.

Irradiance. Light is necessary for germination (Table 2). As the experiment was being conducted, the foil covering one petri dish was removed just enough to check the moisture content of the filter paper. The seeds were exposed to ambient conditions in the greenhouse for less than 10 seconds. When the germination count was done, seeds that were in dark for the entire 21 days had not germinated while

the seeds in the petri dish that had been exposed to light for that brief period of time had germinated, i.e. radicle emergence. When final germination counts were taken for the irradiance treatments, the epicotyl had also emerged, and for many, the cotyledons were also visible.

There was no difference in germination between seeds germinated with continuous irradiance and ambient conditions ($t=.956$, $df=3$). Providing supplemental irradiance during germination is not necessary. In fact, very little total PPF accumulation is required for germination since the seeds in the foil-covered petri dish which received less than 10 sec of ambient greenhouse conditions had germinated. Further research should be conducted to determine the minimum total PPF accumulation required for germination.

pH. Germination on saturated filter paper was dramatically affected by pH. No germination occurred at pH of 4.5 and 5.0 (Table 3). This is similar to the response of ageratum, impatiens, lobularia, petunia and salvia (Shoemaker and Carlson, 1990). Final percentage germination at pH 5.5 to 7.5 was higher than that provided by the seed supplier. This range, pH 5.5 to 7.5, for good germination is broader than the range 5.2 to 6.0 which Koranski (1985) recommends. This difference may be related to different germination procedures or cultivars used.

Changes in germination at the pH levels evaluated were not as evident on peatlite medium compared to filter paper. No minimum pH for germination was evident when seeds were germinated on peatlite medium. Germination increased linearly as pH increased at all pH levels on peatlite medium (Table 3). This difference in germination between seeds germinated on filter paper and on peatlite

medium has also been seen with ageratum, impatiens, lobularia, marigold, petunia, pelargonium, and salvia (Shoemaker and Carlson, 1990).

Conclusions

Begonia semperflorens-cultorum requires light to germinate. Germination greater than the percentage germination indicated by the seed supplier occurred at temperatures from 18 to 32C with 90% or more of the seeds germinating at 18 to 24C and 79 to 83% of the seeds germinating at temperatures greater than 24C. No germination occurred at pH 4.5 and 5.0 while more than 87% germinated over the pH range 5.5 to 7.5 when seeds were germinated on saturated filter paper. When seeds were germinated on peatlite medium, germination of 80% or greater occurred across all pH levels evaluated.

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Table 1. Time distribution of final percent germination of *Begonia semperflorens-cultorum* 'Scarlanda' at different temperatures.

Days after Sowing	Temperature (°C)		
	24	27	32
7	26	75	76
9	72	80	83
11	80	81	87
13	85	81	87
15	87	83	87
17	87	83	87
19	87	83	87

Table 2. Final percentage germination of *Begonia semperflorens-cultorum* 'Scarlanda' as affected by various constant temperatures, and irradiance treatments.

Temperature (°C)						
18	21	24	27	29	32	F
93.3	90.0	93.0	78.8	83.3	83.0	6.58** L 18.59** Q 0.84

Irradiance			
Dark	Continuous[z]	Ambient	F
0	87.2	91.0	2030.26**

[z]50 μmol $s^{-1}m^{-2}$ 24 hr/day.

Table 3. Final percentage germination of *Begonia semperflorens-cultorum* 'Scarlanda' as affected by pH.

Saturated Filter Paper Experiment

pH								
4.5	5.0	5.5	6.0	6.5	7.0	7.5		F
0	0	87	94	84	92	87		59.48**
							L	1.98
							Q	1.79

Peatlite Experiment

pH								
4.5	5.0	5.5	6.0	6.5	7.0	7.5		F
80	87	[y]	80	87	77	87		4.85**
							L	11.39**
							Q	7.75*

[y]The results from the Peatlite Experiment for pH 5.5 were excluded from analysis due to the +0.4 unit increase in pH during the experiment.

SECTION II

Preliminary Studies on the Effects of Irradiance on Growth and Development of *Begonia semperflorens-cultorum*

Candice A. Shoemaker

Department of Horticulture

Michigan State University

E. Lansing, MI 48824

Abstract

Seed of the cultivar 'Scarlanda' begonia were germinated into plug trays (406 14-mm-diameter cells per tray) in controlled environment chambers at a constant 24C with a daily light integral of 10.37 mol $day^{-1}m^{-2}$ (120 μmol $s^{-1}m^{-2}$, 24 hr day^{-1}). The trays were examined on a daily basis for seedling emergence. A seedling was considered emerged when the cotyledons had unfolded to a horizontal position. At 10, 15, and 20 days after emergence seedlings were treated with 160 or 288 μmol $s^{-1}m^{-2}$ (18 and 10 hr day^{-1}, respectively) irradiance for 5, 10, or 15 days. Daily light integral was 10.37 mol $day^{-1}m^{-2}$ for each irradiance treatment. Seedlings were transplanted when all treatments were completed and placed in a controlled environment glass greenhouse with temperature setpoints of 24C day (0800- 1700), 22C night and ambient light conditions. Vegetative and reproductive data were collected when at least 90% of the plants within a treatment were at first flower. Growth differences in response to when the irradiance treatment began show there is a critical time for enhancing begonia seedling development and subsequently, flowering. The timing of the irradiance treatment after emergence influenced leaf number at visible bud, lateral shoot number, flower number, plant height, dry weight, and days to first flower. The two light intensities influenced leaf number and leaf area of the main stem leaf lamina, plant height, leaf area ratio and days to first flower. The higher irradiance plants were taller and had more leaves at visible bud

and first flower than the lower irradiance plants. Leaf area of the main stem leaves and leaf area ratio was greater under the higher irradiance treatment.

Introduction

The production time from seeding to flower for fibrous-rooted-begonia (*Begonia semperflorens-cultorum*) can be as long as 16 weeks (Larson, 1980). Increased popularity of fibrous-rooted begonia has stimulated the need to understand the physiological responses of fibrous-rooted begonia so that management of the growth environment can be improved.

Three developmental phases can be defined for the fibrous-rooted begonia: I - germination, II - germination to transplant (3 expanded leaves), III - transplant to first flower. Environmental factors can influence growth and development differently during each of these phases. Photoperiodic lighting improves the rate and percent of seed germination of most bedding plant species (Piringer et al., 1960; Ogawa et al., 1958; Withrow, 1958), and daily light integral during phase III reduced the production time (Carpenter et al., 1973; Armitage et al., 1979; White et al., 1984; Quatchak et al., 1986).

It is generally recommended to transplant most bedding plant seedlings when they can be easily handled which is when the first true leaves appear (Carlson et al., 1980). While transplanting occurs 3-4 weeks after sowing for most bedding plant species, begonia seedlings can be up to 8 weeks old before they are large enough to handle. Most of the reported studies regarding environmental effects on growth and development of fibrous-rooted begonia has been on the after- transplant phase

(Peterson et al., 1987, Chase and Poole, 1987). Carpenter (1974) reported that with supplemental lighting after germination, begonia seedlings reached the transplanting stage in half the number of days normally required under ambient greenhouse conditions. Days to transplant and flower were decreased when begonia received 24 hr high pressure sodium (HPS) supplemental lighting at 120 μmol $s^{-1}m^{-2}$ for days 10 to 15 or 10 to 20 after emergence (Graper et al., 1987). Petunia and seed geranium have shown a critical period early in development which decreases days to flower and increases plant weight (Graper et al., 1989; Tsujita, 1982).

Graper et al. (1987) evaluated varying daily light integrals and determined that 10.37 mol $day^{-1}m^{-2}$ was most effective to decrease time to flower and increase plant weight. This study was initiated to study growth and development of begonia seedlings during phase II (germination to transplant) with the objectives being to examine responses to: (1) various light intensities with constant daily light integral (DLI), (2) the timing of the irradiance treatment after emergence, and (3) the duration of the irradiance treatment. Constant daily light integral was evaluated rather than varying daily light integral since Graper et al., (1987) determined that 10.37 mol $day^{-1}m^{-2}$ was most effective to decrease time to flower and increase plant weight.

Materials and Methods

Seeds of fibrous-rooted begonia (*Begonia semperflorens-cultorum* 'Scarlanda') were sown on 27 Dec. 1988 into plug trays (406 14-mm-diameter cells per tray) containing a commercial peat-lite medium (Michigan Peat Co.). The trays were covered with a clear plastic dome and placed in a growth chamber at 24C and a photosynthetic photon flux (PPF) of 10.37 mol $day^{-1}m^{-2}$ (120 μmol $s^{-1}m^{-2}$, 24 hr day^{-1}). The PPF was provided by cool-white fluorescent (GE, F48T12, CW 1500) lamps and was measured with a LI-COR LI-185B meter and LI-190SB quantum sensor.

The trays were examined on a daily basis for seedling emergence. A seedling was considered emerged when the cotyledons had unfolded to a horizontal position. An experimental unit consisted of 30 seedlings that had emerged on the same day.

At 10, 15, and 20 days from seedling emergence, plants were exposed to 10.37 mol day^{-1} m^{-2} irradiance of either 288 μmol $s^{-1}m^{-2}$ for 10 hr day^{-1} or 160 μmol $s^{-1}m^{-2}$ for 18 hr day^{-1}. Temperature setpoints were 26C day (0800-1700) and 22C night. The duration of the irradiance treatment was 5, 10, or 15 days. After the irradiance treatment the seedlings were placed in a growth cahmber with temperature setpoints of 26C day (0800-1700), 22C night, and a PPF of 10.37 mol $day^{-1}m^{-2}$ (120 μmol $s^{-1}m^{-2}$, 24 hr day^{-1}).

When all treatments were completed 15 uniform seedlings from each treatment were selected and transplanted individually into 10-cm (450 cm^3) plastic

pots containing a commercial peat-lite medium (Michigan Peat Co.). All plants were placed in a controlled environment glass greenhouse with temperature setpoints of 24C day (0800 to 1700), 22C night and ambient light conditions.

Plants were examined on a daily basis for visible flower buds (3 mm) and first flower. A plant was considered in flower when the petal of one floret of a flower had reflexed to a horizontal position. The experiment was terminated when 90% of the plants within a treatment were at first flower and growth measurements made. Data collected were leaf number at visible bud, final leaf number on the main stem, final plant height, lateral shoot number, leaf area and dry weight.

Data were statistically analyzed as a 2 x 3 x 3 factorial design with light, start of treatment, and duration of treatment as the main factors.

Results and Discussion

The age of the seedlings when lighted was more critical than the light intensity for vegetative development. Leaf number and leaf area of the main stem leaf lamina, plant height, leaf area ratio (LAR) and days to first flower were significantly different at the two light intensities (Table 1). The timing of the irradiance treatment influenced leaf number at visible bud, lateral number, plant height, dry weight and days to first flower (Tables 1-5).

Plants treated with 288 μmol $s^{-1}m^{-2}$ were taller and had more leaves at visible bud and first flower than those treated with 180 μmol $s^{-1}m^{-2}$. Leaf area of the main stem leaves and LAR was greater under the higher irradiance treatment (Table 1).

Growth differences, in response to when the irradiance treatment began, show that there is a critical time for enhancing begonia seedling development and subsequently flowering. Seedlings treated with 180 μmol $s^{-1}m^{-2}$ 10 days after emergence for 15 days flowered in 88 days. Waiting until 20 days after emergence before lighting for 15 days added almost two more weeks to the flowering time (Figure 1a). This difference was not as dramatic at the higher irradiance (Figure 1b).

The duration of the irradiance treatment did not influence days to visible bud and first flower although there was an interaction effect between when the treatment was started and duration of the treatment and an interaction effect between when

the light treatment started and the light intensity (Table 5). Days to first flower decreased as the duration of the lighting increased when lighting began 10 days after emergence. The opposite was true when lighting began 20 days after emergence. When lighting began 15 days after emergence there was a quadratic response to the duration of the irradiance treatment. The longest time to first flower occurred when lighting began 15 days after emergence and lasted for 10 days.

The shortest time to first flower occurred when the irradiance treatment ended by day 25 after emergence (treatment began 10 and 20 days after emergence with treatment duration of 15 and 5 days respectively). This suggests that the critical period for lighting to affect time to first flower would be 10 to 25 days after emergence. Graper and Healy (1987) reported similar results. Time to flower decreased most when supplemental irradiance was provided days 10 to 15 or 10 to 20 after emergence.

It is evident that lighting soon after emergence for a short period of time affects days to first flower. It is not known when the fibrous-rooted begonia first initiates flowers but the results reported here and those reported by Graper and Healy (1987) suggest that it may be within 25 days after the seedling emerges. Morphogenesis studies by Ovchinnikov (1982) support this hypothesis.

Vegetative growth was affected by when the irradiance treatments started as evidenced by plant dry weight, leaf area, primary lateral number, and final plant height (Tables 2 & 3). The interaction between when the irradiance treatments began and the duration of the treatment significantly affected plant dry weight, leaf area and final plant height.

Treatment responses for leaf area and dry weight were similar (Tables 3 &

4). At the starting times and duration of the irradiance treatments evaluated there was a quadratic response when the treatment duration was 5 or 15 days and an increasing linear response when the treatment duration was 10 days. Generally, plants within a treatment which flowered earliest also had the lowest dry weights and leaf areas. If the begonia needed to achieve a certain minimum mass, or a certain number of leaves needed to unfold before flowering could occur then these early light treatments would not have affected flowering time except as they affected rate of vegetative development.

As light intensity increased plant height (main stem length) increased (Figure 2). Plants were up to 2.5 cm taller when treated with high irradiance for only 5 days. Treatment effects on height were not as distinct as for the other vegetative parameters measured. The main effects of light and beginning of the light treatment along with all interaction terms except light x duration were significant (Table 2). Those plants which flowered earliest were not necessarily the shortest nor were those that took the longest to flower the tallest although the relationship of plant size to flowering time was true when considering dry weights and leaf area.

The duration of the irradiance treatment affected the leaf area of the main stem leaf lamina (Table 2). With high irradiance, leaf area increased as the duration of the treatment increased (Table 1). The duration of the treatment showed an interaction with both light intensity and when the treatment began.

Conclusions

Providing irradiance for 10 to 20 days after emergence can be used to increase growth and hasten flowering of fibrous-rooted begonia. The typical cropping time for begonia is 15 to 16 weeks which was reduced to 12 to 13 weeks by lighting only during the early stages of growth. The commercial grower, especially one involved with plug culture, could incorporate lighting at this early stage of development to reduce production time of begonia seedlings.

Due to equipment failure and time constraints this experiment was not replicated over time. Althought the results from this study support previous reported work (Graper and Healy, 1987; Ovchinnikov, 1982) on early lighting of begonia seedlings this experiment can only be considered preliminary work.

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Table 1. The effects of identical DLI delivered over 10 or 18 hrs during different periods from germination to transplant on growth and development of 'Scarlanda' begonia at flower.

PPF[x] (mol $s^{-1}m^{-2}$)	Days post emergence/duration of treatment (days)								
	10			15			20		
	5	10	15	5	10	15	5	10	15
	Main stem length (cm)								
160	11.9	11.3	10.1	11.4	10.6	11.6	10.6	12.9	11.8
288	10.9	11.9	11.5	12.9	10.8	13.5	13.2	14.5	12.1
	Main stem leaf number at visible bud								
160	4.5	4.0	3.9	4.8	4.9	5.3	4.3	4.9	4.9
288	5.2	5.0	4.6	4.8	4.5	5.2	4.8	5.0	5.6
	Average final leaf number								
160	7.4	7.2	7.1	7.1	7.2	8.2	7.1	7.5	7.4
288	7.9	7.7	7.1	7.6	7.5	7.9	7.7	8.2	8.1
	Leaf area of main stem lamina (cm^2)								
160	224.6	215.4	181.8	238.0	218.9	261.4	202.4	238.6	208.3
288	195.5	219.1	256.8	207.0	240.3	294.4	222.1	254.6	239.6
	LAR[y] (cm^2g^{-1})								
160	97.6	88.2	90.8	110.0	108.8	108.3	97.5	87.0	84.40
288	86.9	112.1	129.3	80.7	109.0	117.2	96.0	100.4	113.59

[x]PPF - photosynthetic photon flux.
[y]LAR - ratio of main leaf lamina to whole plant dry weight.

Table 2. Analysis of variance for leaf number and leaf area of the main stem leaf lamina, main stem length[z], and LAR[y] of 'Scarlanda' begonia.

	Leaf number at visible bud		*Final leaf number*[x]		*Main stem length*		*Leaf area of main stem lamina*		*LAR*[y]	
Source	MS	Sign.[w]	MS	Sign.	MS	Sign.	MS	Sign.	MS	Sign.
PPF[v]	5.75	**	6.10	**	4391.84	*	10670.41	**	2778.6	*
Start[u]	2.84	**	1.35	*	2519.82	**	11558.98	**	1231.01	ns
Duration[t]	0.71	ns	0.57	ns	128.33	ns	9714.15	**	2251.10	ns
L x S	3.61	**	0.95	ns	568.89	**	793.08	ns	2437.14	**
L x D	0.19	ns	0.65	ns	87.54	ns	13116.75	**	5820.58	**
S x D	2.61	**	2.54	**	2108.23	**	7260.50	**	503.79	ns
L x S x D	0.33	ns	0.25	ns	832.12	**	3271.49	**	162.22	ns
Error	0.49		0.34		117.29		793.30		507.49	

zMain stem length = plant height (cm).
yLeaf area ratio - ratio of main leaf lamina to whole plant dry weight.
xLeaf number when 90% of all plants were in flower.
wAsterisk indicates significance at 0.05(*) and 0.001(**) level, NS indicates not significant at the 0.01 level.
vLight was 160 and 288 micro mol $s^{-1}m^{-2}$ for 18 and 10 hr d^{-1}, respectively.
uLight treatments started 10,15, or 20 days post emergence.
tDuration of treatment was 5,10, or 15 days.

Table 3. Analysis of variance for leaf area, primary lateral number and plant dry weight of 'Scarlanda' begonia.

	Leaf area number		Primary lateral		Plant dry weight	
Source	MS	Sign.[z]	MS	Sign.	MS	Sign.
PPF[y]	22799.46	ns	1.97	ns	0.01	ns
Start[x]	91647.18	**	2.14	**	0.69	*
Duration[w]	3564.23	ns	0.73	ns	0.09	ns
L x S	7105.24	ns	0.55	ns	0.49	ns
L x D	137.79	ns	0.51	ns	0.49	ns
S x D	48849.92	**	1.13	ns	1.25	**
L x S x D	17520.09	ns	1.16	ns	0.22	ns
Error	9370.59		0.43		0.15	

[z]Asterisk indicates significance at the 0.05(*) and 0.001(***) level, ns indicates not significant at the 0.01 level.
[y]Light was 160 and 288 micro mol $s^{-1}m^{-2}$ for 18 and 10 hr d^{-1}, respectively.
[x]Light treatments started 10,15, or 20 days post emergence.
[w]Duration of treatment was 5,10, or 15 days.

Table 4. The effects of timing of irradiance treatment from germination to transplant on vegetative growth and development of 'Scarlanda' begonia.

PPF[z] (mol $s^{-1}m^{-2}$)	Days post emergence/duration of treatment (days)								
	10			15			20		
	5	10	15	5	10	15	5	10	15
	Leaf area (cm^2)								
160	680.9	658.2	556.4	709.7	632.9	753.1	646.1	765.9	694.9
288	657.8	660.4	654.7	762.0	710.1	753.3	691.7	744.3	668.9
	Primary lateral number								
160	8.6	8.5	9.0	8.9	9.0	9.2	9.0	9.2	9.2
288	9.4	9.2	8.7	9.0	8.8	9.3	8.8	9.9	9.5
	Plant dry weight (g)								
160	2.4	2.4	2.0	2.2	2.0	2.5	2.2	2.8	2.5
288	2.4	2.0	2.1	2.6	2.2	2.5	2.4	2.6	2.4

[z]PPF - photosynthetic photon flux.

Table 5. Analysis of variance for days to visible bud and first flower of 'Scarlanda' begonia.

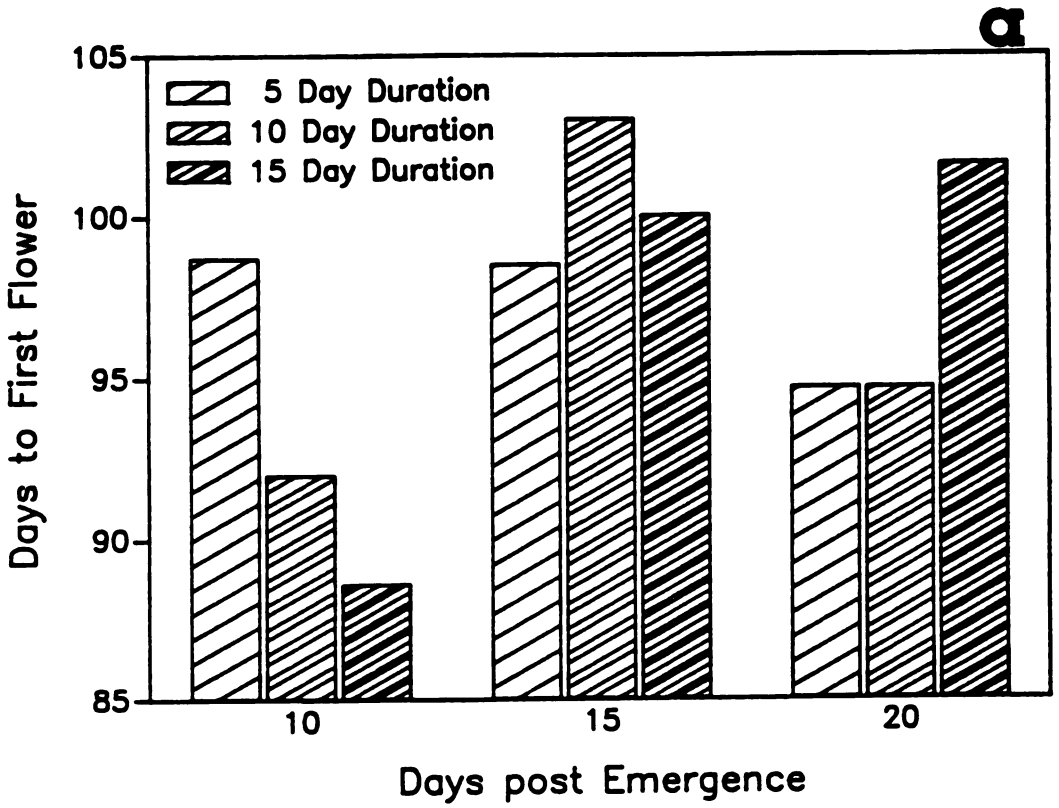
	Visible bud		First Flower	
Source	MS	Sign.[z]	MS	Sign.
PPF[y]	0.06	ns	102.54	*
Start[x]	24.18	ns	158.27	**
Duration[w]	2.97	ns	46.17	ns
L x S	375.67	**	480.85	**
L x D	155.44	**	82.27	ns
S x D	265.75	**	403.98	**
L x S x D	123.84	**	41.76	ns
Error	29.21		28.36	

[z]Asterisk indicates significance at the 0.1 (*) and 0.01(**) level, ns indicates not significant at the 0.01 level.
[y]Light was 160 and 288 micro mol $s^{-1}m^{-2}$ for 18 and 10 hr d^{-1}, respectively.
[x]Light treatments started 10,15, or 20 days after emergence.
[w]Duration of treatment was 5,10, or 15 days.

Figure 1. Days to first flower for 'Scarlanda' begonia treated with two different light intensities at various times after emergence for various lengths of time. D.L.I was equal at all light intensities.

a. Light treatment was 160 μmol $s^{-1}m^{-2}$ for 18 hr day^{-1}.

b. Light treatment was 288 μmol $s^{-1}m^{-2}$ for 10 hr day^{-1}.


a
105
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5 Day Duration
10 Day Duration
15 Day Duration
Days to First Flower
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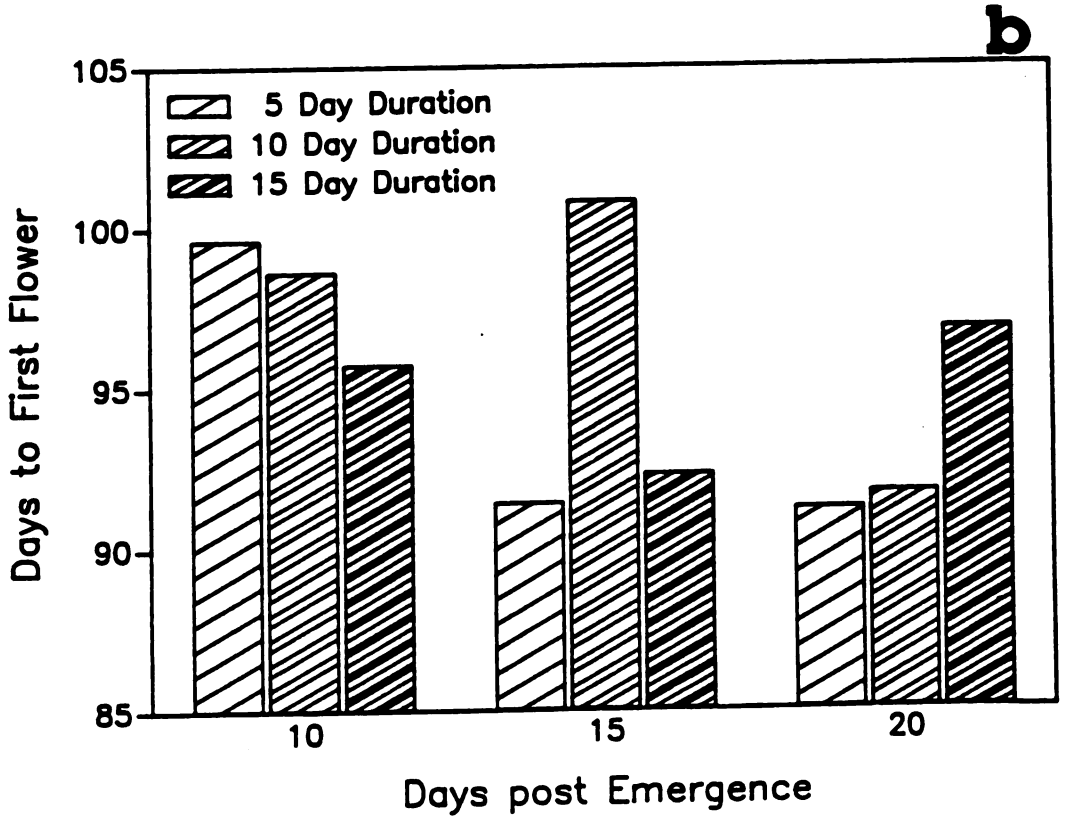
15
20
Days post Emergence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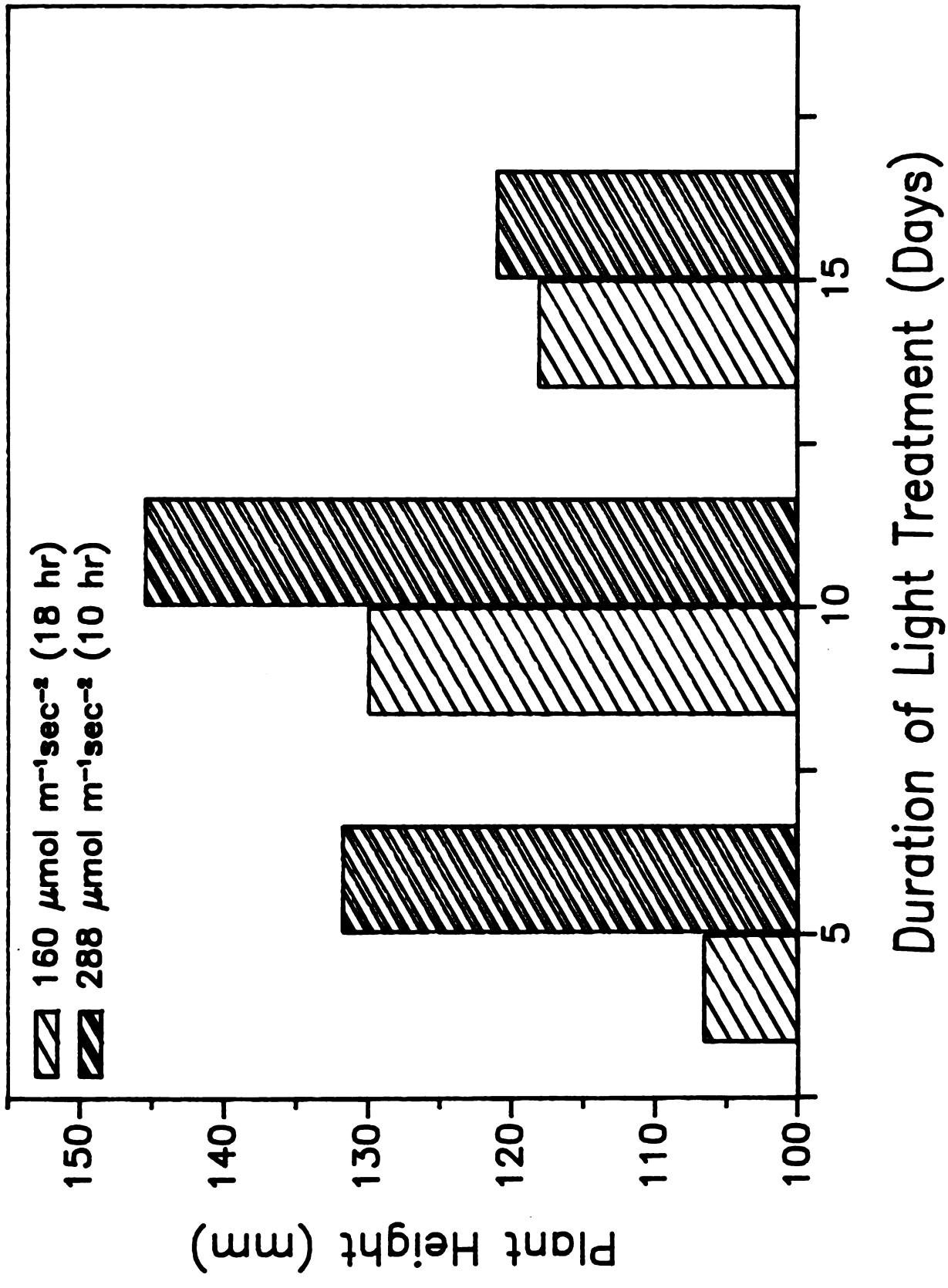
5 Day Duration
10 Day Duration
15 Day Duration
Days to First Flower
10
15
20
Days post Emergence

Figure 2. Plant height (main stem length) for 'Scarlanda' begonia treated with a photosynthetic photon flux of 160 or 288 μmol $s^{-1}m^{-2}$ for 18 and 10 hr day^{-1}, respectively at 20 days after emergence for 5, 10 and 15 days.


160 μmol m⁻¹sec⁻² (18 hr)
288 μmol m⁻¹sec⁻² (10 hr)
150
140
130
120
110
100
Plant Height (mm)
5
10
15
Duration of Light Treatment (Days)

SECTION III

Irradiance and Temperature Effects on Vegetative and Reproductive Development of *Begonia semperflorens-cultorum*

Candice A. Shoemaker

Department of Horticulture

Michigan State University

East Lansing, MI 48824

Abstract

The effects of photosynthetic photon flux (PPF), day temperature (DT), and night temperature (NT) on vegetative and reproductive development was determined for fibrous-rooted begonia (*Begonia semperflorens-cultorum* 'Scarlanda') during phase III which was defined as transplant (3 expanded leaves) to first flower. Temperature treatments were a factorial combination of day and night temperatures at 14, 18, 22, 26, and 30C. Irradiance levels were 50% ambient, ambient (42° lat., Jan. to April, E.Lansing, MI), and ambient plus 3.42 mol $day^{-1}m^{-2}$ supplemental irradiance (0800 - 1730 hrs) delivered with high pressure sodium lamps. The average irradiance level for ambient greenhouse conditions was 9.0 mol $day^{-1}m^{-2}$. Plant height increased less than 2 cm as PPF level was increased. DT and NT influenced plant height, but as with PPF, the treatment differences were only 1 to 2 cm. Average daily temperature (ADT) and the difference between the DT and NT (DIF) did not affect plant height. Primary lateral shoot number increased as temperature and PPF increased. Plants grown with supplemental irradiance reached visible bud ca. 7 days faster, and flower ca. 6 days faster than plants grown under shade. Days to visible bud and days to first flower were a function of NT and PPF. Rate of bud development was also a function of NT and PPF. Bud development rate increased from 14 to 26C and slightly decreased from 26 to 30C. The time from visible bud to flower was a function of NT and PPF. As the NT increased from 14 to 30C, the

time from visible bud to first flower decreased from 21 days to 10 days.

Introduction

Information regarding environmental effects on growth and development of *Begonia semperflorens-cultorum* (fibrous-rooted begonia) is sparse and does not provide adequate parameters for efficient plant production (Peterson et al., 1987; Chase and Poole, 1987). The increased popularity of this bedding plant has stimulated the need to understand the physiological responses of fibrous-rooted begonia so that management of the growth environment can be improved.

Three developmental phases can be defined for the fibrous-rooted begonia: phase I - germination, phase II - germination to transplant (3 expanded leaves), phase III - transplant to first flower. Environmental factors can influence growth and development differently during each of these phases. Photoperiodic lighting improves the rate and percent of seed germination of most bedding plants (Piringer et al., 1960; Ogawa et al., 1958; Withrow, 1958). Carpenter (1974) reported that with supplemental lighting after germination begonia seedlings reached the transplanting stage in half the number of days normally required in the greenhouse under ambient conditions. It has been demonstrated that there is a critical period early in development for supplying supplemental irradiance to decrease days to transplant and flower for begonia and petunia (Graper et al., 1989; Graper et al., 1987; Tsujita, 1982).

Peterson et al. (1987) reported that supplementary HID lighting for two

weeks after transplant reduced production time after transplant from 10 weeks to 6 weeks for begonia. Jeong et al. (1986) suggested that the optimal light intensity for cultivation of Begonia semperflorens be 30 - 45% of natural light intensity (actual light intensities were not reported). Supplemental irradiance has been reported as being important during phase III to reduce time to flower for many bedding plants other than fibrous-rooted begonia (Quatchak et al., 1986; White et al., 1984; Armitage et al., 1979; Carpenter et al., 1973).

Although the effects of day and night temperature on plant growth and development are well documented for a wide range of horticultural species (Heuvelink, 1989; Shanks, 1878; van den Berg, 1984; Armitage et al., 1981; Krizek et al., 1972; Evans, 1963; Went, 1961; Piringer et al., 1961; Miller, 1960) there have been no reports on temperature effects on fibrous-rooted begonia.

This study was initiated to study the sensitivity of plants in phase III (transplant to first flower) with the objectives being to quantify the effects of day temperature (DT), night temperature (NT) and photosynthetic photon flux (PPF) on growth and development of fibrous-rooted begonia.

Materials and Methods

Five-week-old *Begonia semperflorens-cultorum* 'Scarlanda' seedlings were transplanted individually into 10 cm (450 cm^3) plastic pots containing a commercial peat-lite medium (Michigan Peat Co.) on 9 Jan. 1987. All plants were placed in a controlled environment glass greenhouse under ambient (42° lat, E. Lansing, MI) light conditions and a constant temperature of 21C. Initially, plants were irrigated with a 200 ppm N (9N-19.8K-12.4P) fertilizer solution. A 200 ppm N (15N-7P-14.1K) fertilizer solution was applied at subsequent waterings. No growth regulators were applied.

Experimental treatments were initiated seven days after transplanting (on 16 Jan.). Plants were placed in greenhouses with temperature setpoints of 14, 18, 22, 26, or 30C. Each greenhouse section had irradiance levels of 50% ambient (provided with 50% shade cloth), ambient, and ambient plus 3.42 mol day^{-1} m^{-2} (100 μmol from 0800 to 1730 hrs) delivered with high pressure sodium lamps. Plants were moved among greenhouse sections at 0800 and 1700 hrs each day to yield a total of 75 DT/NT/PPF treatment combinations. Movement of plants required approximately 30 min.

Photosynthetic photon flux (PPF) was monitored with a LI-190SB quantum sensor (LI-COR). Actual temperatures and PPF levels were measured every 10 sec. by a datalogger (Digistrip III, Kaye Instruments Co., New Bedford, Conn.) and

averaged to provide hourly mean values. Average temperatures and PPF levels incurred during the experiment were calculated from the hourly means and used in the analyses. Actual average temperatures during the experiment did not vary by more than 1.8C from the desired temperature setpoints. Average PPF levels for the three irradiance treatments were: 50% ambient, 4.4 mol $day^{-1}m^{-2}$; ambient, 9.0 mol $day^{-1}m^{-2}$; and ambient plus supplemental HID, 12.15 mol $day^{-1}m^{-2}$. Leaf temperature, measured at 1200 hrs on a clear day, was +1C for plants receiving supplemental irradiance compared to plants in the 50% ambient and ambient treatments.

The experiment was terminated at flowering or 60 days after the experiment was initiated. Plants were examined on a daily basis for visible bud (3 mm) and first flower. A plant was considered in flower when the petals of one floret of a flower had reflexed to a horizontal position. Data collected on the mother shoot were total plant height, leaf number, lateral number, days to visible bud, and days to anthesis. To take the measurements, the plants were cut at the soil line, the primary lateral shoots were removed and counted, the leaves on the main stem were counted then removed and then the length of the main stem was measured which is reported here as plant height. All of the leaves were removed from the lateral shoots and a total leaf area of the shoots was determined as well as the leaf area of the main stem leaf lamina.

Data were statistically analyzed as a 5 x 5 x 3 factorial design with DT, NT and PPF as the main factors. Regression analysis was performed using the subroutine 'BMDP9R, all possible subsets regression' (Dixon et al., 1985). Models were selected based on the statistical significance of included variables, r^2, and F values of the equations and the adequacy of prediction. All independent variables

included in the final equations were significant at the 5% level as indicated by a two-tailed t test.

Results and Discussion

Plant height. As the PPF level increased from 4.4 mol $day^{-1}m^{-2}$ to 12.15 mol $day^{-1}m^{-2}$ plant height increased slightly, less than 2 cm (Table 1). Although the effect of PPF was statistically significant, the slight difference between the treatments would not make it practical to provide supplemental lighting and or shading for height control.

DT and NT influenced plant height, but as with PPF, the treatment differences were minimal (2 cm or less). Multilinear regression analysis with linear, quadratic and interaction terms of DT, NT, DT-NT(DIF), average daily temperature (ADT), and PPF on plant height yielded a model that accounted for only 40% of the variability in plant height.

$$\text{Plant height} = 56.98 - (0.498 * DIF) + (0.044 * DIF^2) + (0.084 * PPF^2)$$

DT and NT requirements for plant growth were first investigated by Went (1944) who found that maximal growth (stem elongation) occurred when the temperature during the dark period was lower than during the diurnal light period. Thus, the maintenance of DT higher than NT has been the accepted practice in controlled plant cultivation. With the introduction of new developments in greenhouse technology like highly effective thermal screens and computer-based

control systems for greenhouse climate, new control strategies are required for plant production. When thermal screens are used in winter, it can be profitable to use an inverted temperature regime (DT < NT; Leatherland, 1986). Reported research on the inverted temperature regime show that stem elongation was inhibited. This phenomenon was reported in Easter lilies (Erwin et al., 1989), chrysanthemum (Hendriks and Scharpf, 1985; Karlsson et al., 1989), roses (Van den Berg, 1984; Hendricks et al., 1986) and tomato (Heuvelink, 1989).

Erwin et al. (1989) showed that the difference between the DT and NT (DIF=DT-NT) had a greater effect on stem elongation than absolute DT and/or NT. As DIF increases from a negative DIF (DT<NT) to a positive DIF (DT>NT) plant height increases. This was not true with the begonia. In fact, the opposite was true, plants were taller at a negative DIF. For example, when plants were grown at a +12C DIF (DT of 30C with a NT of 18C and ambient light) average plant height was 6.93 cm while plants at a -12C DIF (DT of 18C and NT of 30C and ambient light) had an average height of 8.99 cm (Table 1). The importance of DIF in regards to plant height of begonia was not evident. When DIF was evaluated independently as a linear function of plant height, DIF accounted for only 20% of the variability in plant height among treatment plants. DIF accounted for 78% of the variability in Easter lily plant height at the same DT/NT combinations (Erwin et al., 1989). Heuvelink (1989) concluded that growth reduction at an inverted temperature regime (negative DIF) in comparison with a traditional or constant temperature regime was due to the development of thicker leaves (specific leaf area was lower) at an inverted temperature. Thicker leaves led to less light interception per unit leaf weight and thus to growth and development reduction. Since begonia

produces large leaves and a dense plant canopy, reduction in light interception is probably not a problem, thus growth and development would not be reduced. This may be why we did not see a DIF response with fibrous-rooted begonia.

Primary lateral shoot number. Primary lateral shoot number was a function of ADT and PPF. The effect of temperature and PPF is shown in Figure 1. As temperature increased from 14C to 30C, primary lateral number increased. Supplemental irradiance also increased primary lateral number. This is similar to results for seed geranium (White and Warrrington, 1984).

Visible bud. Time to visible bud decreased with increasing PPF. Plants grown under high intensity supplementary lighting (12.15 mol $d^{-1}m^{-2}$) were at visible bud 21 days sooner than plants grown at 50% ambient (4.4 mol $d^{-1}m^{-2}$) at a DT of 14C and NT of 30C and 17 days sooner at a DT of 30C and NT of 26C (Table 2). This decrease in time to visible bud was not as dramatic when temperatures were not at the extremes. The high PPF level reduced the time to visible bud by ca. 7 days when the temperatures were between 18 and 26C.

Temperature affected days to visible bud. For most treatments, DT and NT of 30 and 14C resulted in the longest time to visible bud. An increase in both DT and NT from 22 to 30C at ambient and 50% ambient delayed time to visible bud by more than 14 days (Table 2).

Days to visible bud is a function of NT and PPF. The developed function predicted fastest development to occur at a NT of 26C and PPF of 12.15 mol $day^{-1}m^{-2}$ (87.69 days). The actual fastest time to visible bud was at a NT of 26C, DT of

22C, and a PPF level of 12.15 mol $day^{-1}m^{-2}$ (Table 2). The effect of NT and PPF is shown in Figure 2. At the high PPF level, predicted time to visible bud did not vary by more than 1 day when the NT increased from 22 to 30C. When the NT increased from 14 to 22C at the same PPF level, however, time to visible bud decreased ca. 18 days. As the PPF level decreased, predicted time to visible bud increased.

Rate of bud development is also a function of ADT, NT, and PPF. The effect of NT on rate of bud development at the three PPF levels evaluated is shown in Figure 3. As PPF increases, rate of bud development increases with the greatest increase occurring between 50% ambient and ambient conditions. As NT increases from 14 to 26C, the rate of bud development increases and from 26 to 30C there is a slight decrease in the rate. Although this decrease in the growth rate was slight, it is similar to developmental rates of other crops (Warrington et al., 1983; Friend et al., 1962).

Visible bud to first flower. The time from visible bud to first flower is a function of NT and PPF. The effect of NT at the three PPF levels evaluated on time from visible bud to first flower is shown in Figure 4. As NT increased from 14 to 30C time from visible bud to first flower decreased from 26 days to 11 days for plants grown at the lowest PPF level. The PPF level had a very slight effect (less than one day difference) when the NT was greater than 24C. These results show that lighting after visible bud is not necessary if the NT is above 24C. Since the begonia is at this stage of development in mid to late spring the warmer night temperatures should not be difficult to maintain in the greenhouse and therefore

supplemental irradiance would not be necessary.

First flower. The average cropping time for the fibrous-rooted begonia is 15 to 16 weeks. By providing 100 μmol $s^{-1}m^{-2}$ supplemental irradiance from 0800 to 1700 after transplant until first flower cropping time was reduced to 13 weeks (14 to 21 days)(Table 2). The importance of providing supplemental lighting after transplant to reduce time to first flower is consistent with previous research reported on begonia and other bedding plants. Peterson et al. (1987) reported that lighting for 2 weeks after transplant reduced time from transplant to first flower by 23 days and by lighting for 4 weeks or more, it reduced production time only 3 to 5 days more. When supplemental lighting was used 1 to 3 weeks after transplanting on impatiens, marigold, petunia, and zinnia, time from transplant to first flower was reduced by 8 to 32 days (Carpenter, 1974).

High temperatures with high irradiance inhibited flowering. Plants grown with DT of 30C and NT of 30 and 26C at the high irradiance did not reach first flower by the conclusion of the experiment. Plants in these environments demonstrated visible signs of stress during the experiment. Leaves were chlorotic with burning along the edges. These results are in agreement with the predictive function for rate of bud development which shows that rate of bud development decreases at temperatures above 26C (Figure 3).

Days to first flower is a function of NT and PPF. The effects of NT and PPF is shown in Figure 5. As NT increases from 14 to 26C, days to first flower decreases by ca. 21 days. Increasing the NT from 26 to 30C results in a slight increase in days to first flower. As the PPF level increases from 4.4 mol $day^{-1}m^{-2}$ to 12.15 mol day

$^{1}m^{-2}$, days to first flower decreases by ca. 30 days. The developed function predicted fastest time to first flower to occur at a NT of 26C with a PPF level of 12.15 mol $day^{-1}m^{-2}$. The actual fastest time to first flower occurred at a NT of 26, DT of 22, with a PPF level of 12.15 mol $day^{-1}m^{-2}$.

These results on reproductive development show that rate of development can be promoted by providing supplemental irradiance, a warm night temperature (26C), and an average daily temperature of 20 to 22C during phase III (transplant to first flower).

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Table 1. Influence of day temperature (DT), night temperature (NT), and photosynthetic photon flux (PPF) on plant height of fibrous- rooted begonia (*Begonia semperflorens-cultorum* 'Scarlanda').

Setpoint (°C)			Actual	Plant height[z](cm)		
DT	NT	ADT[y]	ADT (°C)	PPF[x] mol day^{-1}m^{-2} 4.4[w]	9.0	12.15
30	30	30.0	29.9	5.47	6.05	7.38
30	26	27.5	27.4	5.98	6.63	8.07
30	22	25.2	24.9	5.90	6.69	7.86
30	18	22.7	23.4	5.65	6.93	7.55
30	14	20.3	21.7	5.39	6.21	6.91
26	30	28.4	28.2	5.61	6.54	7.63
26	26	26.0	25.7	5.17	7.31	5.79
26	22	23.5	23.3	5.65	5.55	6.91
26	18	21.2	21.8	5.59	5.94	7.58
26	14	18.7	20.0	5.55	5.36	7.18
22	30	26.8	26.5	7.09	6.39	8.04
22	26	24.4	24.0	5.57	6.46	6.69
22	22	22.0	21.6	6.64	4.99	7.75
22	18	19.5	20.1	5.61	4.94	7.19
22	14	17.2	18.3	7.21	4.00	8.05
18	30	25.2	25.4	7.66	8.99	9.09
18	26	22.8	22.9	6.47	6.92	8.53
18	22	20.4	20.4	6.55	6.59	8.04
18	18	18.0	18.9	6.52	5.99	4.72
18	14	15.5	17.2	6.99	5.78	7.68
14	30	23.7	24.3	7.16	8.33	8.99
14	26	21.2	21.8	7.43	8.87	8.39
14	22	18.8	19.3	6.41	4.43	5.44
14	18	16.4	17.8	6.16	8.47	5.41
14	14	14.0	16.1	6.42	6.51	7.47

[z]Plant height - main stem length from soil line to growing point.
[y]ADT - average daily temperature based on a 9.5 hour day.
[x]PPF - values given in the table are average PPF levels based on hourly means incurred during the experiment.
[w]4.4, 9.0 and 12.15 mol day^{-1}m^{-2} correspond to irradiance treatments of 50% ambient, ambient, and ambient + 3.42 mol day^{-1}m^{-2} supplemental irradiance, respectively.

Table 2. Mean time (days) required for flower development as affected by day temperature (DT), night temperature (NT), and photosynthetic photon flux (PPF) of *Begonia semperflorens-cultorum* 'Scarlanda'.

Setpoint DT (°C)	Setpoint NT (°C)	Actual ADT (°C)	Actual ADT[z] (°C)	Days to Visible Bud PPF[y] mol day^{-1}m^{-2} 4.4[x]	9.0	12.15	Days to First Flower PPF mol day^{-1}m^{-2} 4.4	9.0	12.15
30	30	30.0	29.9	116.0	106.7	*[w]	*	109.0	*
30	26	27.5	27.4	103.0	96.4	86.0	109.5	104.2	*
30	22	25.2	24.9	104.5	92.0	90.6	115.7	99.6	101.7
30	18	22.7	23.4	101.4	97.4	95.4	120.2	115.0	109.3
30	14	20.3	21.7	110.8	106.4	103.2	123.0	120.0	125.0
26	30	28.4	28.2	109.7	99.2	100.0	120.0	107.0	107.0
26	26	26.0	25.7	99.0	91.8	91.8	110.3	100.3	100.0
26	22	23.5	23.3	95.9	92.6	91.0	111.0	109.4	107.0
26	18	21.2	21.8	99.6	93.2	94.2	107.5	111.0	108.0
26	14	18.7	20.0	109.0	96.6	93.6	120.0	120.3	113.3
22	30	26.8	26.5	107.8	93.4	103.6	117.7	101.3	113.5
22	26	24.4	24.0	99.6	92.8	82.8	110.5	97.7	93.7
22	22	22.0	21.6	101.2	89.6	84.0	116.2	103.0	97.2
22	18	19.5	20.1	96.8	95.4	87.6	112.0	106.7	100.0
22	14	17.2	18.3	99.8	105.0	99.0	120.0	122.7	114.3
18	30	25.2	25.4	106.5	95.2	99.6	115.7	99.0	106.0
18	26	22.8	22.9	93.6	91.0	86.4	105.3	102.7	98.0
18	22	20.4	20.4	94.6	89.0	88.8	109.7	103.8	102.2
18	18	18.0	18.9	101.6	95.2	93.0	120.6	112.2	105.3
18	14	15.5	17.2	107.6	103.2	99.8	*	115.0	120.0
14	30	23.7	24.3	112.5	92.0	91.0	*	101.0	95.0
14	26	21.2	21.8	101.4	90.4	99.4	109.0	103.5	109.7
14	22	18.8	19.3	101.2	93.6	90.6	116.2	106.7	105.0
14	18	16.4	17.8	96.4	96.6	94.6	122.0	114.0	108.0
14	14	14.0	16.1	110.2	103.8	99.0	*	*	*

[z]ADT - average daily temperature based on a 9.5 hour day.
[y]PPF - values are average PPF levels based on hourly means.
[x]4.4, 9.0 and 12.15 mol day^{-1}m^{-2} correspond to irradiance treatments of 50% ambient, ambient, and ambient + 3.42 mol day^{-1}m^{-2} supplemental irradiance, respectively.
[w]Asterisk indicates plants in that treatment did not reach first flower by the conclusion of the experiment.

Figure 1. The effect of average daily temperature (ADT) and photosynthetic photon flux (PPF) on number of primary lateral shoots formed in fibrous-rooted begonia (*Begonia semperflorens-cultorum* 'Scarlanda'). The functional relationship used to create the graph was: Primary lateral shoot number = 4.95 + (0.14 * ADT) - (0.45 * PPF) + (0.027 * PPF^2); $r^2=0.65$, cp=3.10.

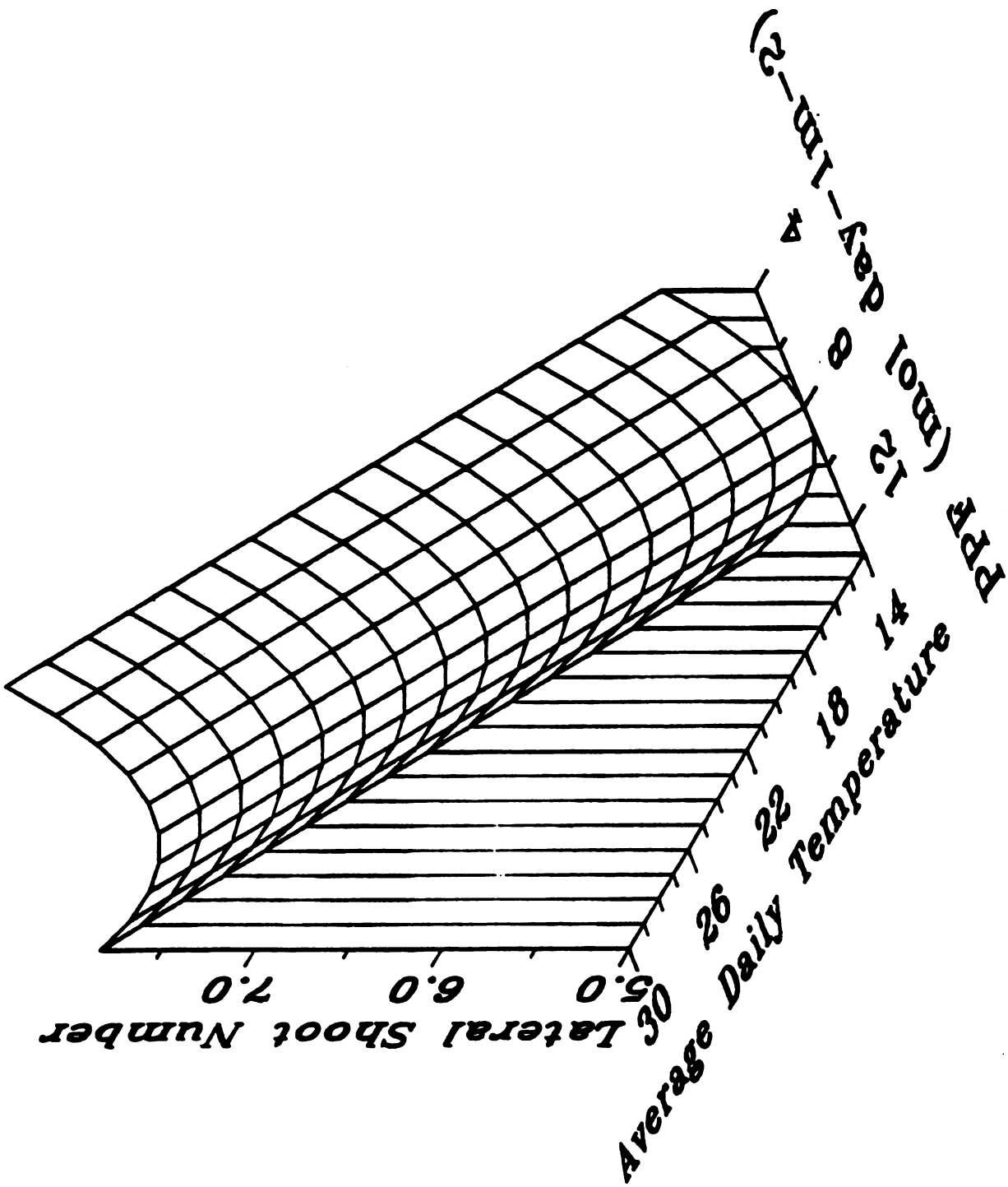

Lateral Shoot Number
5.0
6.0
7.0
Average Daily Temperature
30
26
22
18
14
Root Dry Weight (g)
0
2
4

Figure 2. The effect of night temperature (NT) and photosynthetic photon flux (PPF) on days to visible bud (3 mm) in fibrous-rooted begonia (*Begonia semperflorens-cultorum* 'Scarlanda'). The functional relationship used to create the graph was: Days to visible bud = 185.245 - (5.72 * NT) - (4.26 * PPF) + (0.116 * NT^2) + (0.166 * PPF^2); $r^2 = 0.71$.

Days to Visible Bud
87
93
99
105
111
Night Temperature
14
18
22
26
30
PPF (Mol day-1 m-2)
4
8
12

Figure 3. Number of fibrous-rooted begonia (*Begonia semperflorens- cultorum* 'Scarlanda') flower buds per day as affected by night temperature (NT) and photosynthetic photon flux (PPF). The functional relationship used to create the graph was: Rate of bud development = (0.00155) + (0.00057 * NT) + (0.0004 * PPF) - (0.000011 * NT^2) - (0.000015 * PPF^2);r^2=0.70.

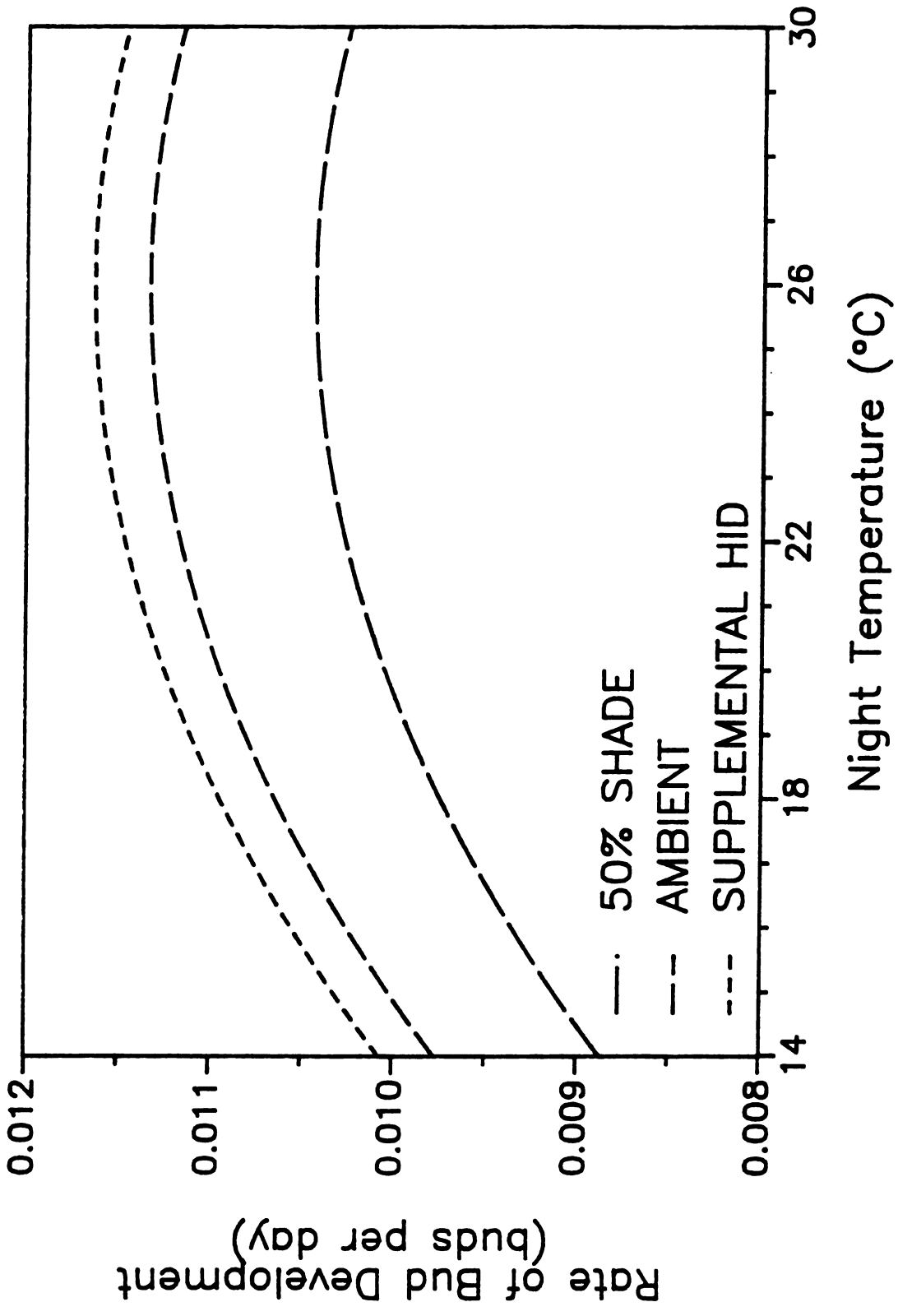

Rate of Bud Development
(buds per day)
0.012
0.011
0.010
0.009
0.008
14
18
22
26
30
Night Temperature (°C)
50% SHADE
AMBIENT
SUPPLEMENTAL HID

Figure 4. The effect of night temperature (NT) and photosynthetic photon flux (PPF) on days from visible bud to first flower in fibrous-rooted begonia (*Begonia semperflorens-cultorum* 'Scarlanda'). The functional relationship used to create the graph was: Days from visible bud to first flower = 72.054 - (4.018 * NT) - (1.169 * PPF) + (0.065 * NT^2) + (0.044 * NT * PPF); r^2=0.66.

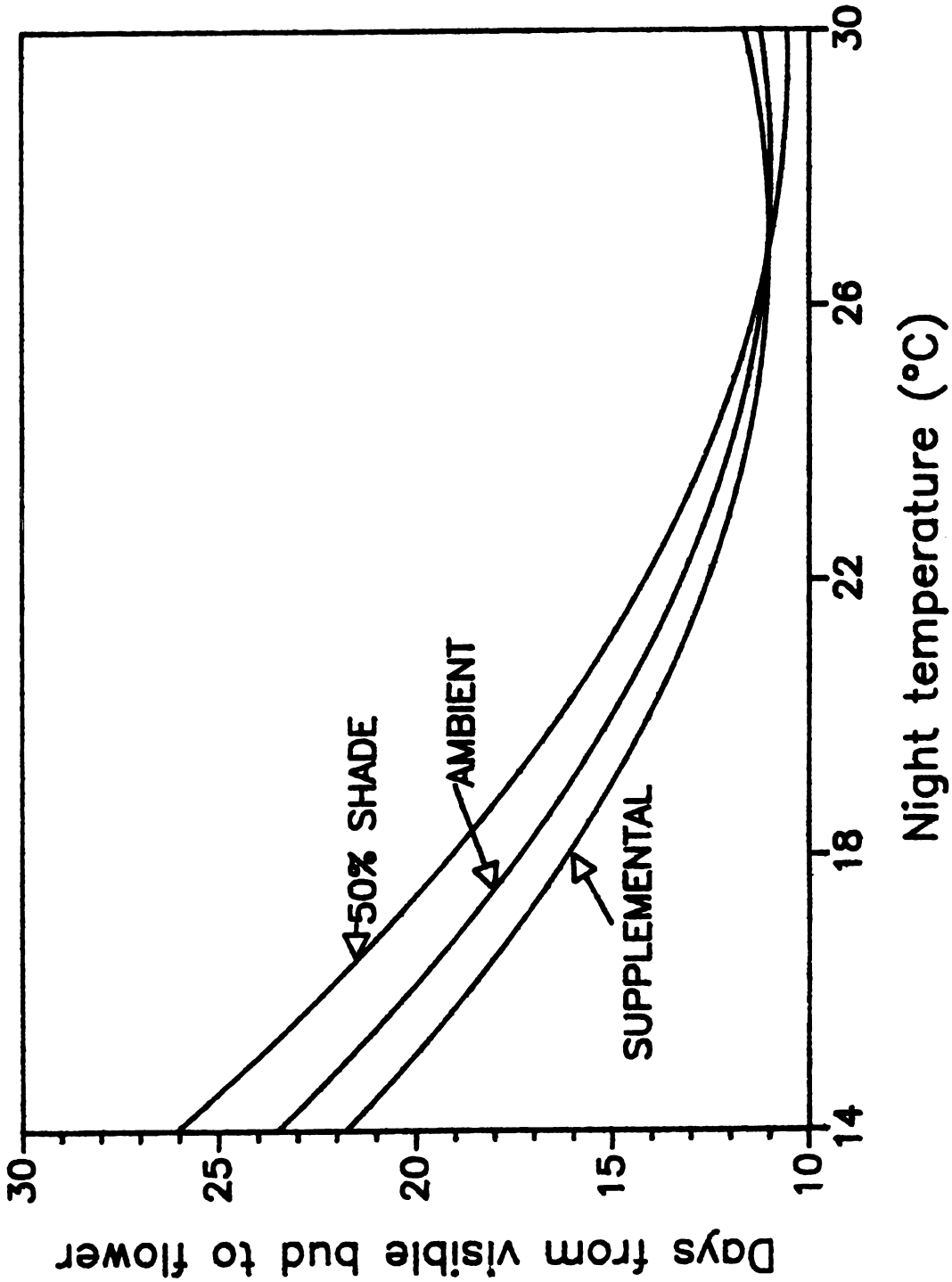

Days from visible bud to flower
30
25
20
15
10
14
18
22
26
30
Night temperature (°C)
50% SHADE
AMBIENT
SUPPLEMENTAL

Figure 5. The effect of night temperature (NT) and photosynthetic photon flux (PPF) on days to first flower in fibrous-rooted begonia (*Begonia semperflorens-cultorum* 'Scarlanda'). The functional relationship used to create the graph was: Days to first flower = 220.64 - (7.44 * NT) - (3.19 * PPF) + (0.14 * NT^2) + (0.11 * PPF^2); r^2=0.74.

Days to Flower
99 107 115 123 131
Night Temperature
14 18 22 26 30
PPF (Mol day-1 m-2)
4 8 12

APPENDIX A

Determining floral initiation of *Begonia semperflorens-cultorum* using scanning electron microscopy

The time of floral initiation in *Begonia semperflorens-cultorum* has not been determined. Early lighting promotes flower initiation in seed geranium (Armitage, 1978) and hastens flowering in begonia (Graper and Healy; 1989). Will lighting of begonia early in seedling development promote flower initiation?

Preliminary work, using scanning electron microscopy, to determine flower initiation of begonia was done. Seeds of begonia were sown on 7 June 1989 into plug trays (406 14-mm-diameter cells per tray) containing a commercial peat-lite medium (Michigan Peat Co.). The trays were covered with a clear plastic dome and placed in a growth chamber at 24C and a photosynthetic photon flux (PPF) of 10.37 mol $day^{-1}m^{-2}$ (120 μmol $s^{-1}m^{-2}$, 24 hr day^{-1}). The PPF was provided by cool-white fluorescent (GE, F48T12, CW 1500) lamps and was measured with a LI-COR LI-185B meter and LI-190SB quantum sensor.

The trays were examined on a daily basis for seedling emergence. A seedling was considered emerged when the cotyledons had unfolded to a horizontal position. When more than 50% of the seedlings had emerged, PPF was increased to 160 μmol $s^{-1}m^{-2}$ for 18 hr day^{-1}, day temperature (0800-0200) was 24C, and night temperature was 22C.

At seedling emergence, 14, 25, and 42 days from seedling emergence, 10 seedlings of uniform size were prepared for scanning electron microscopy (SEM).

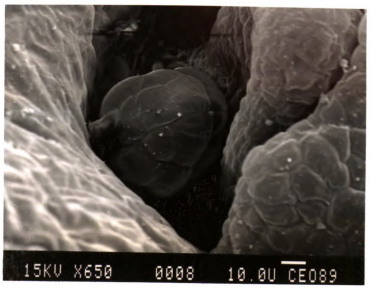
Transition from a vegetative to reproductive state occurred between days 14 and 42 after seedling emergence (Fig. 1 and 2). Further work is required to determine exactly when the transition occurs and how irradiance and temperature can influence it. Also, techniques in specimen preparation for electron microscopy need to be refined.

Figure 1. Shoot apex of *Begonia semperflorens-cultorum* 'Scarlanda' 14 days after seedling emergence.

a. magnification x650

b. magnification x1300

a



b

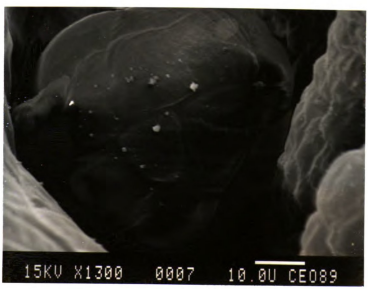
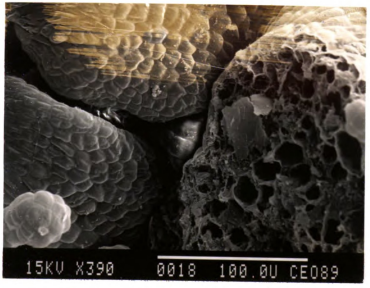


Figure 2. Shoot apex of *Begonia semperflorens-cultorum* 'Scarlanda' 42 days after seedling emergence.

a. magnification x390

b. magnification x1000

a



b