Light Governs the Germination of *Impatiens wallerana* Hook. f. Seed

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Abstract. The role of light on *impatiens* seed germination and radicle emergence was studied. Seeds having a photodormancy require light for only part of the germination period. Germination $\geq 85\%$ was achieved after 3, 2, or 1 day of irradiance at 1.5, 15, or 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, respectively. Keeping imbibed seeds in darkness for ≥ 2 days before light exposure caused reduced total germination percentages (G), delayed achieving 50% of the final germination percentage (T_{50}), and increased the days between 10% and 90% germination ($T_{90} - T_{10}$). Light for 6 hours daily at 1.5, 15, or 150 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ promoted high G and rapid and uniform germination, but daily 12 to 24 hours of irradiance decreased G and increased T_{50} and $T_{90} - T_{10}$. Estimated rates of decline (increase) in G, T_{50} , or $T_{90} - T_{10}$ with each added day of light (darkness) or increasing daily hours of light were measured by fitting regression equations. *Impatiens* seed germination was promoted by the initial 1 to 3 days of light, but light inhibited radicle extension in the latter germination stages.

Impatiens is the most widely grown annual, flowering, bedding plant. Cathey (1976) reported that continuous light was required to achieve maximum germination, but Ball (1985) recommended continuous light with uniform temperature (24 or 25°C) and medium moisture content. Toole (1973) reported that light acts in dormancy induction or release of seed and often interacts with temperature. Exposing imbibed seeds to white light for seconds or minutes does not inhibit or promote germination; rather, irradiation or darkness is needed for many hours (Bewley and Black, 1982). Khan (1977) found light sensitivity varies among individual members in a seed population. Some seeds in each lot were inhibited by a few hours of light, whereas the germination of other seed was prevented only by light exposure for many hours or continuously.

Phytochrome, a photochemically reactive pigment found in seeds, is responsible for light sensitivity (Bewley and Black, 1982). The outer living layers of the seed, including the testa, nucellus, or endosperm, that adjoin the embryo are the locations of physiological active tissue for the reception of light (Hartmann et al., 1990). Exposing imbibed seeds to white or red light causes phytochrome P_R to change

to phytochrome P_{FR} , which stimulates the germination of seeds requiring light. Exposing seed to far-red light or prolonged darkness causes a change to the alternate form (P_R), which prevents germination of seeds requiring light. Bewley and Black (1982) reported that seeds requiring light under long-term illumination with white light had initial seed dormancy broken by light. However, the radicle extension was inhibited in the latter germination stages by the same duration of irradiation. It has not been determined if phytochrome contributed to this radicle extension inhibition. Our objectives were to determine if the light irradiance level and periods of light or darkness of varying lengths could influence total germination, germination rate, and uniformity in germinating *impatiens* seed.

Materials and Methods

Lighting and germination procedures. 'Accent Orange' *impatiens* seed was used in all studies because $\approx 81\%$ of the seed required light for germination and seedlings had exceptional vigor. In preliminary studies, 'Lipstick', 'Accent Pink', 'Super Elf Coral', 'Red Velvet', and 'Accent Red' had 82%, 75%, 43%, 23%, and 10% of seeds requiring light, respectively, with more days to 50% of final germination (T_{50}) values than 'Accent Orange'. Goldsmith Seeds, Gilroy, Calif., provided seeds 8 weeks after harvest. Treatments contained four 100-seed replications in all studies, with replicates germinated in individual 9-cm petri dishes on anchor blue blotter paper 100 saturated with 6 ml of distilled water. Seeds were dusted with 3 α ,4,7,7 α -tetrahydro-2-[(trichloromethyl)thio]-1-*H*-isolindole-

1,3(2*H*)-dione (captan) before germination in incubators (model 17-5RG; Stults Scientific Engineering, Springfield, Ill.). The incubators were equipped with timeclocks to control the period of light durations and incandescent dimmers (Lutron Co., Coopersburg, Pa.) to establish light irradiance levels from 60-W incandescent lamps. Petri dishes were placed on a shelf 3 cm above the incubator floor, and 1.5, 15, or 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ irradiance levels were monitored using a quantum-radiometer (LI-COR 185A; LI-COR, Lincoln, Neb.). In all studies, *impatiens* seeds were germinated at 25°C, but 24 and 23°C incubator air temperatures were required during periods of lighting at 15 and 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, respectively, to maintain 25°C in petri dishes. Petri dishes were rotated daily within and among chambers of the same irradiance level during periods of lighting, although light irradiance among locations within incubators never exceeded $\pm 4\%$ from the established level.

In each study, daily germination counts were made of seeds with radicle protrusion through the testa. Germination counts of seeds in darkness required several minutes daily in the dim light of a 25-W green lamp (0.21 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ photosynthetically active radiation). Total germination percentages (G), T_{50} , and germination span in number of days between 10% and 90% germination ($T_{90} - T_{10}$) were calculated from the data as described by Furutani et al. (1985).

We performed analysis of variance on data and fitted regression (linear and quadratic) equations to determine if trends in G, T_{50} , and $T_{90} - T_{10}$ values were present after seed treatment at various light irradiance levels and days of light (or darkness). In every study, the light irradiance level and the period of lighting (or of darkness before light) were interrelated—the effect of each depended on the setting of the other factor. Consequently, to measure the effect of lighting duration (or duration of darkness before light), separate equations were fitted at each irradiance level. Similarly, trends across the irradiance levels were obtained by fitting separate equations at each level of lighting duration (or each level of darkness before light). A strictly linear trend was detected, indicating that the rate of increase (decrease) in the average G, T_{50} , or $T_{90} - T_{10}$ values was constant over the period of lighting or the range of light irradiance levels. We also detected a quadratic trend, indicating that the rates of increase (decrease) in the average G, T_{50} , $T_{90} - T_{10}$ values were not constant but varied over the period of lighting or the range of light irradiance levels. Trends were tested at $P \leq 0.10$, 0.05, and 0.01, respectively; the lower the *P* value, the stronger the trend.

Period of light duration. In the initial study, imbibed seeds received 1, 2, 3, 4, 5, 6, 7, or 8 days of light at 1.5, 15, or 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, followed by continuous darkness during germination. In a second study, imbibed seeds received continuous darkness or light at 15 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ during germination or 2 days of light at 15 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ followed by continuous darkness. Daily counts were made of seeds

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with emerged radicles, and average G , T_{50} , and $T_{90} - T_{10}$ values were taken across the four replicates.

Period of darkness before light. In this study, imbibed seeds were kept in darkness during the initial 2, 4, 6, or 8 days of germination, followed by continuous light for 3 days at 1.5, 15, or 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ and then darkness during the remainder of the 28-day germination period. Seeds of another treatment were not kept in darkness before the 3 days of light, followed by continuous darkness during the 28-day germination period. Seeds were germinated at 25C during periods of light or darkness. Methods for germination counts and data analyses using regression equations were similar to those used in the first study.

Irradiance level and daily photoperiod. Seeds germinating at 25C received irradiation at 1.5, 15, or 150 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ for 0, 1, 6, 12, 18, or 24 h daily from incandescent lamps during the 28-day germination period. This investigation was conducted as three studies, with the irradiance level 1.5 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ in incubators during the initial study, followed by 15 or 150 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$. Incubator air temperatures were kept at 24C to maintain 25C in petri dishes during periods of lighting at 15 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ irradiation and 23C at 150 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$.

Results

Period of light duration. 'Accent Orange' impatiens seed had differing G depending on light or darkness. Germination percentages at 6 and 8 days of light did not differ from those at 4 days of light at any irradiance level (data not shown). Germination percentages generally increased as the days of lighting increased from 1 to 4 and the level of irradiance increased (Table 1). Three days of light at 1.5 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ were required to achieve 87% germination, but 15 and 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ required 2 and 1 days, respectively, to obtain this level. At each irradiance level, G increased quadratically with increasing light duration. Germination percentages for seed receiving 2 days of light were 20%, 13%, and 3% higher than for seed receiving only 1 day of light at 1.5, 15, and 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, respectively. With ≥ 3 days of light, germination percentages ranged from 87% to 91% across the light irradiance levels. G increased significantly ($P \leq 0.05$) with increasing irradiance level only at 1 and 2 days of light (Table 1). The second study showed that $\approx 19\%$ of 'Accent Orange' seed did not require light (Fig. 1). Two days of continuous light at 15 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ was adequate to satisfy the light requirement and promote 86% germination. Continuous light at 15 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ during the 14-day germination period resulted in G at 47% (Fig. 1).

Increasing the duration of irradiance at 1.5 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ from 1 to 8 days had no effect on T_{50} values but reduced $T_{90} - T_{10}$ values (Table 2). At 15 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, average T_{50} and $T_{90} - T_{10}$ values increased linearly as the period of light increased from 1 to 8 days. Seeds receiving 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ irradiance had the highest T_{50} and $T_{90} - T_{10}$ values during 4- to 8-day

Table 1. The influence of irradiance level and days of light exposure on the total germination percentages of 'Accent Orange' impatiens seeds at 25C. Germination percentages are means of four 100-seed replications. Results of tests for trends across days of light and irradiance levels are indicated.

Irradiance level ($\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$)	% Germination				Significance	
	Days of light				Linear	Quadratic
1.5	59	79	87	90	***	**
15	72	85	88	91	**	**
75	86	89	91	90	*	**
Linear	**	**	NS	NS		
Quadratic	**	NS	NS	NS		

NS, *, **, ***Nonsignificant or significant at $P \leq 0.1$, 0.05, or 0.01, respectively.

Fig. 1. Cumulative germination curves with days to 50% germination (T_{50}) and days from 10% to 90% germination ($T_{90} - T_{10}$) for impatiens seeds in (□) continuous darkness T_{50} , 3.6 days; $T_{90} - T_{10}$, 2.3 days; (×) continuous light at 15 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ irradiance; T_{50} , 6.8 days; $T_{90} - T_{10}$, 5.4 days; or (●) 2 days in light then darkness at 25C; T_{50} , 4.2 days; $T_{90} - T_{10}$, 2.6 days. Percentages are the means of four 100-seed replications.

Table 2. The influence of level and days of irradiance on the number of days to 50% germination (T_{50}) and the number of days from 10% to 90% germination ($T_{90} - T_{10}$) for 'Accent Orange' impatiens seeds at 25C. Results of tests for trends across days of light and irradiance levels are indicated.

Germination measurement	Irradiance level ($\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$)	Days to germination					Significance	
		Days of light					Linear	Quadratic
T_{50}	1.5	5.1	5.1	5.0	4.9	5.0	NS	NS
	15	4.1	4.2	4.5	5.1	5.2	***	NS
	75	4.0	4.9	6.2	6.9	7.3	***	**
Linear		NS	NS	***	***	***		
Quadratic		***	***	***	NS	NS		
$T_{90} - T_{10}$	1.5	3.6	3.2	2.8	2.8	3.0	**	***
	15	2.5	2.6	3.9	4.8	5.1	***	NS
	75	2.3	2.8	3.3	4.3	5.6	***	**
Linear		**	NS	NS	NS	***		
Quadratic		***	***	***	***	***		

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

periods of lighting, with T_{50} and $T_{90} - T_{10}$ values increasing linearly as lighting duration increased.

Dark period before light. The germination response of impatiens seed to light was modified when imbibed seeds were kept in darkness for 2 to 8 days before irradiance (Table 3). When G was modeled as a function of number of days in darkness at each irradiance level, G decreased linearly as number of days in darkness before light increased. The daily rate of decrease in G at 1.5 and 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ was greater ($P \leq 0.01$) than at 15 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$. Curvilinear trends in G across the 1.5, 15, or 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ irradiance levels occurred only with continuous light and 8 days of darkness before light (Table 3). At 2, 4, and 6 days of darkness before light, germination percentages were similar at the three irradiance levels.

T_{50} values increased as the days in darkness before light increased at each irradiance level (Table 3). At 15 or 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, T_{50} values increased linearly with increased days in darkness before light, but at 1.5 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, the increase in T_{50} was greatest at 0 to 4 days and remained constant at 4 to 8 days. When modeled across the irradiance levels at each period of darkness, T_{50} increased linearly with increasing irradiance for seed that received 0 to 4 days of darkness before light, although at 6 and 8 days of darkness before light, a greater increase in T_{50} was observed between 1.5 and 15 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ than was observed between 15 and 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$.

At each irradiance level, $T_{90} - T_{10}$ increased with increased number of days in darkness before light (Table 3). At 15 and 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, the $T_{90} - T_{10}$ values increased linearly with increased days of darkness, but at 1.5 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, the increase in $T_{90} - T_{10}$ values occurred mainly between 0 and 4 days of darkness and remained constant at 4 to 8 days of darkness.

Seeds in darkness for 0, 2, and 4 days had $T_{90} - T_{10}$ values that increased linearly with increasing irradiance levels from 1.5 to 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$. Seeds in darkness for 6 and 8 days had similar $T_{90} - T_{10}$ values at 15 and 75

$\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ that were higher than the $T_{90} - T_{10}$ value at 1.5 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$.

Irradiance level and daily photoperiod. G changed curvilinearly as the daily photoperiod increased at each level of irradiance (Fig. 2A, Table 4). At 1.5 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, G increased from 79% to 92% when the light duration increased from 1 to 6 h daily. Then G decreased to 73% as the photoperiod increased from 6 to 24 h daily. At 15 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, G increased 3% with 1 to 6 h of light daily and declined by 44% with continuous light. At 150 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ of light daily, G was 95% at 1 h and decreased curvilinearly to 20% with continuous light. With increased irradiance, G increased quadratically at 1 h of light daily but decreased with ≥ 6 h of light daily. The rate of G decline with increased irradiance accelerated with more hours of light daily.

Values in days to T_{50} changed curvilinearly with increasing daily photoperiod at 1.5 and 150 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ (Fig. 2B, Table 4). At 15 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, T_{50} values increased linearly with increasing photoperiod. At ≥ 12 h of light daily, the T_{50} values increased linearly with increasing irradiance levels (Table 4).

$T_{90} - T_{10}$ increased with an increase in the number of hours of light daily (Fig. 2C, Table 4). At 1.5 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, the $T_{90} - T_{10}$ values changed curvilinearly, but at 15 or 150 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, the trends in $T_{90} - T_{10}$ values were linear (Fig. 2C). At 1 h of light daily, $T_{90} - T_{10}$ decreased quadratically with increased light irradiance. At 6 h of light daily, no difference in $T_{90} - T_{10}$ at the different irradiance levels was detected. With a daily photoperiod of ≥ 12 h, $T_{90} - T_{10}$ values generally increased linearly with increasing irradiance levels.

Discussion

Many of the light-controlled germination responses found in their search with impatiens have been associated previously with the action of phytochrome. The irradiance level and days of light during germination were found to control the G, T_{50} , and $T_{90} - T_{10}$ responses. Impatiens seeds receiving irradiance at 1.5,

15, or 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ required 3, 2, and 1 day, respectively, to achieve 85% to 87% total germination. Bewley and Black (1986) reported that up to the saturation value, the effect of light is directly proportional to the total amount of energy received, irrespective of how the energy is delivered. When the total light energy from irradiance level $\times$ time are equal, then the percentage of seeds breaking dormancy and rates of germination should be similar. Therefore, at high irradiance levels, seeds require fewer hours of light daily and

Fig. 2. Plots and regression equations relating (A) total germination percentage (G), (B) days to 50% of final germination (T_{50}), and (C) days between 10% and 90% germination ($T_{90} - T_{10}$) to daily photoperiod at (●) 1.5, (□) 15, and (+) 150 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ irradiance levels, respectively.

Table 3. The effect of 2 to 8 days in darkness before 3 days of irradiance at 1.5, 15, or 75 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ on total germination (G), days to 50% germination (T_{50}), and days from 10% to 90% germination ($T_{90} - T_{10}$) of imbibed 'Accent Orange' seed. Values of G, T_{50} , and $T_{90} - T_{10}$ are means of four 100-seed replications. Results of tests for trends across days of darkness and irradiance levels are indicated.

Measurement	Irradiance level ($\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$)	Days of darkness					Significance	
		0	2	4	6	8	Linear	Quadratic
G(%)	1.5	93	84	64	50	34	***	NS
	15	89	87	69	55	43	***	NS
	75	91	87	66	48	38	***	NS
Linear		NS	NS	NS	NS	NS		
Quadratic		*	NS	NS	NS	**		
T_{50} (days)	1.5	5.1	5.9	6.3	6.4	6.3	**	***
	15	5.4	5.8	6.9	7.8	8.0	***	NS
	75	7.4	7.7	8.3	8.6	9.2	***	NS
Linear		***	***	***	***	***		
Quadratic		NS	NS	NS	***	***		
$T_{90} - T_{10}$ (days)	1.5	2.8	4.0	4.6	4.8	4.9	**	***
	15	4.1	5.0	7.3	8.7	9.6	***	NS
	75	5.4	7.3	8.8	8.9	9.6	**	***
Linear		***	***	***	**	**		
Quadratic		***	NS	***	***	***		

NS, **, *** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

Table 4. The effect of 1.5-, 15-, or 150- $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ irradiance levels for 1 to 24 h daily on the total germination (G), days to 50% germination (T_{50}), and days from 10% to 90% germination ($T_{90} - T_{10}$) of 'Accent Orange' impatiens seed at 25C. Values of G, T_{50} , and $T_{90} - T_{10}$ are means of four 100-seed replications. Results of tests for trends across daily photoperiod and irradiance levels are indicated.

Measurement	Irradiance level ($\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$)	Daily photoperiod (h)					Significance	
		1	6	12	18	24	Linear	Quadratic
G (%)	1.5	79	92	87	78	73	**	***
	15	88	91	78	63	47	***	***
	150	95	88	80	58	20	***	***
Linear		**	**	**	***	***		
Quadratic		***	NS	**	NS	NS		
T_{50} (days)	1.5	4.4	4.1	4.3	4.4	4.7	**	**
	15	3.7	4.1	5.0	5.8	6.8	***	NS
	150	5.0	6.6	8.0	8.3	8.7	***	***
Linear		***	NS	***	***	***		
Quadratic		***	NS	NS	*	NS		
$T_{90} - T_{10}$ (days)	1.5	4.3	3.8	3.9	4.3	5.1	***	***
	15	3.3	3.8	4.2	4.8	5.4	***	NS
	150	2.8	3.6	5.1	5.3	6.9	***	NS
Linear		***	NS	***	***	***		
Quadratic		***	NS	NS	*	NS		

NS, *, **, *** Nonsignificant or significant at $P \leq 0.1$, 0.05, or 0.01, respectively.

fewer days to germinate. Our results show commercial, bedding plant producers that providing $\geq 75 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ irradiation for 1 day to break the light-related seed dormancy of 'Accent Orange' impatiens is better than giving lower irradiance intensities for several days.

Light to terminate seed dormancy must be received at a critical stage during seed germination. The maximum response from irradiating imbibed impatiens seeds occurred during the first day of germination. Imbibed seeds kept in darkness for 2 to 8 days before receiving light for 3 days had progressively lower G and higher T_{50} and $T_{90} - T_{10}$ values. Bewley and Black (1982) associated the reduced G of lettuce (*Lactuca sativa* L.) seed, receiving light after 24 h in darkness, to the inhibitory effect caused by the operation of the phytochrome system in its classical low-energy mode. Taylorson and Hendricks (1976) reported that curly dock (*Rumex crispus* L.) and henbit (*Lamium amplexicaule* L.) seeds, two light-sensitive species, enter a secondary or induced dormancy when they were kept in darkness after imbibition. In species requiring light for promoting germination, secondary dormancy is manifested by failure of seed to germinate after normally adequate periods of irradiance. When imbibed seeds are kept in darkness for several days or more, they become deeply dormant and have much reduced or lower sensitivity to light or gibberellin treatment (Vidaver and Hsiao, 1973). Follow-

ing the establishment of dormancy, the germination response to light can only be restored by either cold treatment or brief periods of high temperatures (Taylor and Hendricks, 1973).

Impatiens seeds receiving light for 12, 18, or 24 h daily throughout germination had reduced G and delayed germination at each of the irradiance levels tested. The extent of change increased with photoperiod (Fig. 2). Bewley and Black (1982) have attributed the inhibitory effects of continuous light on G, T_{50} , and $T_{90} - T_{10}$ throughout germination to the low $P_{fr} : P_{Total}$ ratio of phytochrome that occurs under prolonged irradiance. The inhibition in seed germination during continuous lighting has the characteristics of the high-energy or the high-irradiance reaction of photomorphogenesis, which also controls many aspects of plant growth and development. Seeds are susceptible to delayed or inhibited germination by light just before and during the time when cells of the radicle are about to elongate; thus, the inhibitory effect of light is probably on cell elongation (Bewley and Black, 1982).

Our studies should help horticulturists to better understand the frequent reports of low and irregular germination of impatiens seed. Ball (1985) and Cathey (1976) recommended light during impatiens seed germination, but they give no guidelines for the irradiation level or lighting duration. Our data showed that 'Accent Orange' had $\approx 19\%$ of the seed capable of germination in darkness, but the dor-

mancy of this light-requiring seed could be terminated by incandescent light for 1 day at $75 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ or 2 days at $15 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ irradiance levels (Table 1). Continuous light during germination lowered G and increased T_{50} and $T_{90} - T_{10}$ values by delaying radicle emergence (Fig. 1). Thus, irradiating light-requiring seeds throughout germination breaks their dormancy, but later during germination, their radicle extension is inhibited by irradiation at the same level. Based on our results, we recommend that commercial impatiens producers light the seeds at 15 or $75 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ for 2 or 1 day, respectively, initially after moistening the germination substrate. Then place the seeds in darkness until emergence of the epicotyl.

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