Flowering Responses of Petunia Plants to Photoperiod and Irradiance

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Summary

Various flowering responses in Petunia × hybrida Vilm. ‘Garden Party White’ and ‘Snow Cloud White’ were studied under different photoperiods and irradiance levels. In particular, leaf number below the first flower bud (LNBFB) on the main stem, time to macroscopic flower bud visibility (MFBV), time to anthesis, time to flower bud development, and the percentage of flower bud abortion were examined. LNBFB increased significantly (P<0.001) only under a combination of short-day (SD) and low irradiance, but each had little effect alone. Time to MFBV and time to anthesis decreased, as photoperiod or irradiance increased. One of the main factors on late anthesis under unfavourable light condition appears to be flower bud abortion. In this study, photoperiod or irradiance had no effect on LNBFB, but they influenced the time to anthesis either singly or together, indicating that long-day (LD) and/or high irradiance is necessary for minimizing a production period of petunia plants.

Key Words: flowering, irradiance, Petunia × hybrida, photoperiod.

Introduction

Flowering in Petunia × hybrida Vilm. has previously been examined by some workers (Piringer and Cathey, 1960; Adams et al., 1999) and they claimed that it was a quantitative LD plant because LD advanced anthesis, while SD delayed it. They also suggested that flowering responses in petunia were not completely fixed but changeable under various combinations of environmental factors. Most of the previous works focused on time to anthesis but little on LNBFB. Recently, Adams et al. (1999) reported on the chronological duration of juvenile phase in petunia plants but did not mention LNBFB.

In general, flowering is understood as producing an open flower, but “flowering” is scientifically not a clear term. Flower initiation and flower bud development are also considered to be a process of flowering (Kinet, 1993). In many cases, time to flowering is chronologically measured as counting the actual number of days to anthesis. This method does not necessarily consider the first flower bud formed since the bud does not always reach anthesis. To observe the initial microscopic flower bud, on the other hand, dissecting the terminal bud is necessary; hence it is not possible to evaluate time to anthesis using the same plants. However, counting the number of leaves formed below the first flower bud enables the physiological duration to flower initiation to be measured (Vince–Prue, 1975) and to estimate vegetative growth made prior to flower initiation (Roberts and Summerfield, 1987). The leaf number is usually minimal under an optimal condition, but plants remain vegetative and form more leaves under unfavourable conditions.

Effects of irradiance on time to anthesis in petunia were demonstrated by Kaczperski et al. (1991) with combinations of various day and night temperatures. They reported that the plants grown under high irradiance generally reached anthesis earlier than under low irradiance, but they did not examine LNBFB. It is yet unknown whether or not LNBFB is affected by photoperiod or/and irradiance. In this study various flowering responses were examined to seek the minimal time to produce commercial petunia plants.

Materials and Methods

All experiments were performed at the Sutton Bonington Campus, University of Nottingham (United Kingdom), and propagation methods were basically identical between experiments. The seeds of Petunia × hybrida ‘Garden Party White’ and ‘Snow Cloud White’ were sown onto separate seed-trays containing fine peat compost. The trays were then placed in a greenhouse under natural daylight and kept at 20 °C. After germination, the seedlings were individually transplanted to a plastic pot (9 cm diam.) filled with peat compost. These were regularly irrigated with 1% w/v liquid fertilizer solution (N:P:K = 19:19:19). Treatments commenced before the fifth or sixth true leaf was visible since petunia plants with six expanded leaves seemed to be already sensitive to photoperiod (Piringer and Cathey, 1960). All experiments were performed in the green-
house at a mean temperature of 20 ± 3°C.

Measurements of flowering responses were almost identical between treatments. Days to MFBV and anthesis were recorded when these occurred on a main stem or on a lateral branch. Time from MFBV to anthesis was determined by deducting days to MFBV from days to anthesis. The first flower bud did not always open first. LNBFB, excluding cotyledons, was counted only on the main stems since it varied greatly between branches even in the same plant. At the end of the treatment, plants were harvested and the number of aborted flower buds was counted, and then the percentage was calculated. The flower bud abortion was macroscopically observed, as a dead corolla exposed when the sepals had opened outward (Shimai, 1998). Data were subjected to analysis of variance (ANOVA) using Genstat 3.2.

Experiment 1. Flowering responses to photoperiod

Plants of ‘Garden Party White’ and ‘Snow Cloud White’ were exposed to photoperiods of 8, 10, 12, 14, and 16-hr, using an automatic opaque curtain system, which closed from 17:00 to 9:00 the following morning. All plants received 8-hr daylight each day without additional lighting, and the photoperiods were extended by 100 W tungsten bulbs (TL) (0.7 W·m⁻²) either 2, 4, 6, or 8-hr, except for the 8-hr photoperiod. Five plants of each cultivar were allocated in each treatment. The treatments commenced on 22 September 1997 and continued until all plants in each treatment reached anthesis, or terminated at 80 days later.

Experiment 2. Flowering responses to irradiance

Plants of ‘Garden Party White’ were exposed to three irradiance levels (no-shading, 25% shading, and 50% shading) in the greenhouse; the two lower irradiance levels were created by shading nets. The mean irradiance levels at plant height were 110, 64, and 44 W·m⁻², respectively. The irradiance levels at a photosynthetically active radiation level (PAR) between 400 and 700 nm were monitored hourly and recorded by a data logger. The treatments were started on 9 September 1996 and continued for 60 days. At the beginning of treatments, the photoperiod was approximately 13-hr and gradually decreased. No additional lighting was given in this experiment. Each treatment was replicated 3 times with 5 plants.

Experiment 3. Flowering responses to the interaction between photoperiod and irradiance

Seedlings of two cultivars were given four treatments: combinations of two photoperiods and two irradiance levels. All plants under SD treatments received natural daylight only from 8:00 to 16:00 daily, whereas plants under LD treatments received additional low irradiance from TL (0.7 W·m⁻²) until 24:00. Two irradiance levels, no-shading and 50% shading, were superimposed on each photoperiod. Mean irradiance levels (PAR) recorded by a data logger at plant height in each treatment were 78.9 W·m⁻² in LD + no-shading, 43.0 W·m⁻² in LD + 50% shading, 81.3 W·m⁻² in SD + no-shading, and 42.3 W·m⁻² in SD + 50% shading; i.e. regardless of the photoperiods, irradiance levels were very similar within no-shading or within 50% shading treatments. The treatments commenced on 22 September 1997 and continued until all plants in each treatment reached anthesis, or terminated 80 days later.

Results

Flowering responses to photoperiod

A highly significant (P<0.001) difference on LNBFB was found between ‘Garden Party White’ and ‘Snow Cloud White’; the former produced two or three more leaves below the first flower bud than the latter. No effects of photoperiod on LNBFB were evident. However, a highly significant (P<0.001) interaction between photoperiod and cultivar was found on MFBV (Table 1). ‘Snow Cloud White’ reached MFBV significantly (P<0.001) earlier than ‘Garden Party White’ in all treatments. ‘Snow Cloud White’ showed less clear responses between the treatments while ‘Garden Party White’ linearly decreased time to MFBV as the photoperiod was extended. Under the 16-hr photoperiod, MFBV occurred at 13.9 days in ‘Snow Cloud White’ and 19.8 days in ‘Garden Party White’; under the 8-hr, MFBV occurred at 16.8 days and 35.1 days, respectively, indicating that photoperiod alone had an effect on time to MFBV. Time to anthesis depended upon photoperiod or/and cultivars. ‘Snow Cloud White’ always reached anthesis earlier than ‘Garden Party White’. In the 8-hr treatments, no anthesis occurred in ‘Garden Party White’. When the photoperiod was longer than 14-hr, time to anthesis was shortened, but this tendency was much clearer in ‘Garden Party White’, decreasing approximately 40 days. The main reason for the delay or lack of anthesis was flower bud abortion. Time from MFBV to anthesis that decreased in LD treatments supported the assumption. In all plants, flower buds were initiated but further flower development was hindered under SD. For example, when the photoperiod was 10-hr or shorter, over 90 percent of flower buds aborted.

Flowering responses to irradiance

No significant irradiance effects were seen on LNBFB among the three treatments (Table 2). Time to MFBV was highly significantly (P<0.001) affected by irradiance, MFBV occurring at 27.9 days under no-shading, and at 32.6 days under 50% shading. Highly significant (P<0.001) effects of irradiance were also found on time to anthesis. Without shading, plants reached anthesis at 44 days, but by 50% shading, no anthesis occurred. This lack of anthesis is attributed to flower bud abortion under 50% shading because all
plants in all treatments formed flower buds, indicating that flower bud development depends upon irradiance. Time from MFBV to anthesis between no-shading and 25% shading treatments was statistically different (P<0.001). The development of flower buds was greatly affected by irradiance in ‘Garden Party White’ (Table 2).

**Flowering responses to the interaction between photoperiod and irradiance**

A significant (P<0.01) interaction between photoperiod and irradiance on LNBFB was found. Approximately 15 leaves were formed in ‘Snow Cloud White’ and 18 leaves in ‘Garden Party White’ under all treatments, except the combination of SD and 50% shading, where a slight but significant (P<0.01) increase in leaf number was seen. On time to MFBV, there was a highly significant (P<0.001) interaction between photoperiod and cultivar, but other interactions were not evident (Table 3). LD resulted in earlier MFBV; in particular, ‘Snow Cloud White’, which was always earlier than ‘Garden Party White’. In LD + no-shading, the difference between the two cultivars was rather small, but the difference increased as irradiance decreased. In the two SD treatments, time to MFBV was similar in each cultivar. On time to anthesis, there was an interaction between photoperiod and irradiance (P<0.01) and between photoperiod and cultivar (P<0.01); in both LD treatments, the two cultivars reached anthesis, but anthesis was almost completely inhibited under SD. The main reason for this was again flower bud abortion. In LD treatments, time from MFBV to anthesis was unaffected by irradiance, meanwhile almost no anthesis took place in SD treatments.

**Discussion**

This research examined various flowering responses of petunia plants to photoperiod, irradiance, and their
interaction to seek the minimum time required for commercial production. Neither photoperiod nor irradiance had a significant effect on LNBFB, but SD at low irradiance tended to increase the number of leaves. A similar result was reported in *Lycopersicon esculentum*, where the number of leaves to the first inflorescence increased only under SD with low irradiance (Kinet, 1977). The minimum number of leaves defining the end of juvenility differs among species. As few as 2 leaves in *Pharbitis nil* (Imamura, 1967), 6 to 8 in *Senecio × hybridus* (Yeh and Atherton, 1977), and 6 to 12 in *Daucus carota* (Atherton et al., 1990) were required for flower initiation; the number is usually constant within a cultivar. In this study, the minimum LNBFB was generally between 13 and 17, depending upon cultivar or experiment, suggesting that those are the minimum number of leaves needed before the juvenile phase ends. The results were somewhat inconsistent with those of Adams et al. (1999), who found that the juvenile phase was irradiance-dependent. The difference could be explained by the use of other methods to estimate the length of the juvenile phase with different cultivars.

All plants in all treatments produced flower buds in this study so that the time to MFBV was affected by either photoperiod or irradiance, and there is little evidence that an interaction between them occurred. Although no previous studies have focused on effects of photoperiod on time to MFBV in petunia, Maginnes and Langhans (1961) and Harris and Ashford (1966) reported that LD hastened the process in *Antirrhinum majus* and in *Dianthus caryophyllus*, respectively. It is suspected that far-red light from TL, which accelerated shoot elongation, may have affected the rate of flower bud development. Effects of far-red light on flower development have been confirmed by Holland and Vince (1971). The difference was also seen between the cultivars, implying that one cultivar behaves differently from the other. ‘Garden Party White’ is a multiflora-type that bears smaller but more flowers, while ‘Snow Cloud White’ is a grandiflora-type that bears larger but fewer flowers. The highest irradiance level in this study was 110 W·m⁻² that resulted in the earliest MFBV, but it lengthened as irradiance decreased. The first flower bud was initiated when a relatively constant number of leaves were formed in all treatments, except in the combination of SD and low irradiance, indicating that photoperiod is not the only factor for the flower initiation.

Time to anthesis was generally reduced by longer photoperiod as previously reported by Piringer and Cathey (1960) and Adams et al. (1999). However, it may not just be a photoperiodic effect but one of light quality, since petunia plants grown in 8-hr daylight followed by 8-hr cool fluorescent light did not respond differently from those grown under an 8-hr photoperiod (Shimai, 1998). A possible explanation for this could be that flower bud abortion was prevented and corolla development was accelerated by far-red rich TL. Far-red light is known to modify the inner hormonal level, enhancing corolla development of plants (Beall et al., 1996; Vince-Prue, 1975). Thus the time to anthesis was either greatly lengthened or anthesis did not occur under

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**Table 3. Interaction effects between photoperiod and irradiance on flowering responses in two petunia cultivars.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cultivar</th>
<th>LNBFB²</th>
<th>MFBV³</th>
<th>Anthesis⁴</th>
<th>MFBV to anthesis⁵</th>
<th>Flower bud aborted (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LD +</td>
<td>Snow Cloud White</td>
<td>15.0</td>
<td>13.9</td>
<td>30.5</td>
<td>16.6</td>
<td>16.3</td>
</tr>
<tr>
<td>No–shading</td>
<td>Garden Party White</td>
<td>17.7</td>
<td>19.8</td>
<td>35.3</td>
<td>15.5</td>
<td>8.0</td>
</tr>
<tr>
<td>LD +</td>
<td>Snow Cloud White</td>
<td>15.2</td>
<td>14.1</td>
<td>33.8</td>
<td>19.7</td>
<td>50.7</td>
</tr>
<tr>
<td>50% shading</td>
<td>Garden Party White</td>
<td>17.5</td>
<td>23.7</td>
<td>40.8</td>
<td>17.1</td>
<td>34.7</td>
</tr>
<tr>
<td>SD +</td>
<td>Snow Cloud White</td>
<td>15.6</td>
<td>16.8</td>
<td>33.0</td>
<td>16.2</td>
<td>99.6</td>
</tr>
<tr>
<td>No–shading</td>
<td>Garden Party White</td>
<td>17.9</td>
<td>36.3</td>
<td>NA</td>
<td>NA</td>
<td>100.0</td>
</tr>
<tr>
<td>SD +</td>
<td>Snow Cloud White</td>
<td>17.2</td>
<td>18.8</td>
<td>NA</td>
<td>NA</td>
<td>100.0</td>
</tr>
<tr>
<td>50% shading</td>
<td>Garden Party White</td>
<td>19.0</td>
<td>35.4</td>
<td>NA</td>
<td>NA</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**Significance**

Photoperiod (P)  *** synaptic *** synaptic *** ***
Irradiance (I)   ** NS NS NS
Cultivar (C)     *** synaptic *** NS NS
P × I            ** NS NS *
P × C            * *** NS NS
I × C            * NS NS NS
P × I × C        NS NS NS NS

²,³,⁴,⁵ See explanations under Table 1.
⁶ NS, ***, **, and * indicate no significance and significance at P<0.001, 0.01, and 0.05, respectively.
low irradiance. Kaczperski et al. (1991) also found that more days were required for anthesis under low irradiance, but did not count the number of flower buds aborted.

Flower bud abortion more frequently occurred when plants were grown either in short photoperiod or in low irradiance. In this study, lowering irradiance to 44 W·m⁻² increased the rate of flower bud abortion, whereas at 110 W·m⁻² only 15 percent of flower buds aborted. Similarly, Lycopersicon esculentum failed to develop the flower buds under low irradiance (Kinet, 1977).

In conclusion, photoperiod or irradiance had little effects on LNBFB, although one or both govern flower bud development. The current study shows that flower bud abortion is directly associated with the delay of anthesis in petunia plants, so that preventing flower bud abortion is critical in flower production and enhancing flower quality.

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Literature Cited


ベチュニアの日長と光強度に対する開花反応

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摘　要

異なる日長、光強度の下でベチュニア‘ガーディーン・パーティー・ホワイト’と‘スノー・クラウド・ホワイト’の様々な開花反応に関する研究を行った。特に主茎上の最初に形成された花蕾より下の葉数（LNBFB）と、花蕾が肉眼で観察できるまでの時間（MFBV）、開花までの時間、花蕾発達に要する時間、および花蕾のアボート率に着目した。

短日と低い光強度の組合せ下のみでLNBFBが増加し、日長または光強度のみの影響は統計上認められなかった。MFBVと開花までの時間は、日長または光強度が増すにつれて短くなった。不適当な光条件下で開花が遅れる原因の一つは、花蕾のアボートによるものである。本研究結果においてLNBFBには、日長または光強度のみの影響はみられなかったが、開花までの時間では、どちらか一方、または両方が影響していた。これらはベチュニアの生産期間を短縮するうえで、長日または高い光強度が不可欠であることを示唆する。