Effects of Light Quality, Intensity and Duration from Different Artificial Light Sources on the Growth of Petunia (Petunia × hybrida Vilm.)

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Summary

The effect of light quality on the growth of petunia (Petunia × hybrida Vilm.) ‘Baccarat Blue Picotee’ was studied. Petunias were grown in growth chambers under a metal halide (MH), high pressure sodium (HPS) and blue (B) lamps, at different light intensities and duration, additionally, these were sprayed with GA3 and Uniconazol, a growth retardant.

1. Plant shapes were more compact under HPS than under MH or B. The longest lateral shoot under HPS was about 30% shorter than that of plants grown under MH or B. The average internode length was also shorter under HPS than the others; this result is attributed to the high-red : far-red light ratio (R/FR) of HPS, which was mediated by plant phytochromes.

2. Light intensities also influenced plant height, which increased with decreasing light intensity under MH and HPS. Furthermore, plant height and stem length under HPS were shorter than those under MH in all light intensities.

3. The rate of shoot elongation was reduced when the plants were transferred from MH to HPS. The final light quality determined the plant height. But, it had no residual effect.

4. The growth inhibition by HPS was reversible by the application of GA3. Whereas, Uniconazol had no effect on stems exposed to HPS. These results suggest that the high R/FR ratio of HPS inhibits GA synthesis and, therefore, plant height was shorter than plant exposed to which has a lower R/FR ratio.

Key Words: blue light, high pressure sodium lamp, light quality, metal halide lamp, petunia.

Introduction

As a primary energy source to plants, light is an indispensable factor for plant growth, but the morphogenesis of plants is strongly affected by light quality. The effect of light on plant growth which has been studied by many researchers, has shown that not only light intensity but also light quality is important for the growth, development, pigment synthesis and shape of plants. Tomato (Helson, 1965) and lettuce (Knight and Mitchell, 1988) demonstrated that plant growth under a combination of incandescent and fluorescent lighting was better than that under a fluorescent lamp alone.

Light qualities affect photomorphogenesis, e.g., the stem growth was influenced by the red light to far-red light ratio (R/FR) (Fukuda et al., 1993; McMahon et al., 1991; Rajapakse and Kelly, 1992). Phytochromes that are involved in photomorphogenesis mediate the ratio of red to far-red light perceived by plants; e.g., cell elongation of wheat in the dark was inhibited by red light and promoted by far-red light (Bleiss and Smith, 1985). Our previous study, show that the stem elongation of a tomato plant was inhibited under yellow light (HPS lamp) more than under white light (MH lamp), and dry matter partitioning to the stem under yellow light was also decreased (Fukuda et al., 1993). We suggested that, in the tomato, the high R/FR ratio of HPS decreased the dry matter partitioning to the stem and made the stem short. Rajapakse and Kelly (1992) who studied the control of chrysanthemum growth found that a spectral filter (CuSO4 filter) decreased FR spectrum in sunlight. They have reported that the plant height and internode length were shorter, and the dry matter partitioning to the stem was less in chrysanthemums grown under CuSO4 filter than in control plants. Kubota et al. (2000) also reported that red–light-rich spectral treatment under photo–selective films produced petunia with short main stem.
GA biosynthesis and/or action are probably affected by the light quality (Rajapakse and Kelly, 1992). Weller et al. (1994) has shown that sensitivity to GA could be altered by phytochrome. But the mechanism of stem growth inhibition by the irradiation of high R/FR ratio light remains to be elucidated.

Because light quality affects plant growth and morphogenesis, artificial lights have been used to control flowering, and supplemental lighting to promote photosynthesis and extend the day length.

Previously, we investigated the effects of light quality on the growth of petunias using following color of lights: white (control), red, yellow, green and blue lamps, and found that plant height and stem length of petunia were shorter under the yellow lamp (HPS) than those under the white lamp (MH) (Yoshinaka et al., 1998). The objectives of this study were 1) to investigate the light-quality effects of MH, HPS and blue lamps on the growth of petunia; 2) to determine the interaction between light quality and light intensity on the growth of petunia; and 3) to examine the effects of different light duration of these light sources. In addition, the interactions between light treatment and GA₃ and Uniconazol spraying were analyzed.

**Materials and Methods**

**Plant material**

Seeds of *Petunia × hybrida* Vilm. ‘Baccarat Blue Picotee’ (Sakata Seed Corporation, Yokohama, Japan) were sown on moist vermiculite. This cultivar is a dwarf type with medium sized flowers. The growth chamber was partitioned into six compartments, and each compartment had its set of lights (Fig. 1). After seeds germinated in a greenhouse, the seedlings were transplanted individually in 10cm pots filled with vermiculite and clay soil (2:1, v/v). The seedlings were fertilized with commercial fertilizer (Hyponex, N:P₂O₅:K₂O =10:8:8, Hyponex Japan, Osaka, Japan). After treatment, a second commercial fertilizer (Promic, N:P₂O₅:K₂O =5:10:5, Hyponex Japan) was applied.

**Light sources**

A metal halide lamp (MH, D400; Toshiba), high pressure sodium lamp (HPS, NH360FD-L; Toshiba) and specially designed metal halide lamp (B, Toshiba) that irradiated blue light all provided by Toshiba Co., Ltd. (Tokyo, Japan) were used as the artificial light sources. Spectral quantum distributions of the light sources were measured with a spectroradiometer (LI-1800, Li-Cor, Lincoln, Neb., USA) (Table 1). The lamps were hung above a neutral filter equipped on the top of the growth chamber (1.2 × 1.5 m) (Fig. 1). Air temperature in the chamber was kept at 24/20°C (day/night). Plants were subjected to a 12-hr photoperiod. During the experiments, the overhead lamps were adjusted to provide 100, 200 or 400 μmol·m⁻²·s⁻¹ (PPF; photosynthetic photon flux) at the top of the plants. The light intensity was measured with a quantum sensor (LI-190 SA, Li-Cor, Lincoln, Neb., USA).

**Experiment 1. Effect of light quality on petunia growth**

After transplantation to pots, the plants were transferred to the chambers with MH or HPS that irradiated 400 μmol·m⁻²·s⁻¹ light intensity. After the plants

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**Table 1.** Relative quantum distribution in percentages of total quantum, and relative quantum ratio from each light source.

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</tr>
</thead>
<tbody>
<tr>
<td>MH</td>
<td>0.17</td>
<td>42.4</td>
<td>7.5</td>
<td>7.6</td>
<td>9.0</td>
<td>18.3</td>
<td>16.3</td>
<td>41.3</td>
<td>1.1</td>
<td>0.41</td>
<td>0.46</td>
</tr>
<tr>
<td>HPS</td>
<td>0.01</td>
<td>58.3</td>
<td>2.6</td>
<td>2.0</td>
<td>18.7</td>
<td>35.0</td>
<td>12.1</td>
<td>29.8</td>
<td>2.9</td>
<td>0.07</td>
<td>0.21</td>
</tr>
<tr>
<td>B</td>
<td>0.07</td>
<td>52.9</td>
<td>32.6</td>
<td>8.4</td>
<td>4.5</td>
<td>7.4</td>
<td>7.6</td>
<td>39.5</td>
<td>1.0</td>
<td>4.41</td>
<td>4.31</td>
</tr>
</tbody>
</table>

The quantum distribution was measured with spectroradiometer (LI-1800, Li-Cor, Lincoln, Neb., USA).
were grown for 45 days, the dry matter weight of shoots, number of lateral shoots, longest lateral shoot length, stem diameter, number of nodes, corolla radius, floral tube length and peduncle length were measured. The fifth internodes of the longest lateral shoots were collected and fixed in FAA for 6 hr, for the anatomical study. Samples were dehydrated with a tertiary butyl alcohol series, embedded in water soluble resin (JB-4, Polyscience, Illinois, USA), and sectioned to 20 μm thickness. Sections were stained with 1% acid fuchsin and examined with a photomicroscope (BH-2, Olympus, Tokyo, Japan).

Experiment 2. Effects of light quality and light intensity on petunia growth

Uniform plants with 6 to 7 true leaves were selected and transferred to six compartments with MH or HPS. For each light source, we set up three light intensity levels; low (100 μmol·m⁻²·s⁻¹), medium (200 μmol·m⁻²·s⁻¹), or high (400 μmol·m⁻²·s⁻¹) level at the top of the plants. After the treatments, the petunias were grown for 45 days. Throughout this growth period, the number of days to flowering was recorded, plant height and plant canopy diameter were measured at 10 day intervals. Plant canopy diameter was measured as the maximum width of the plant canopy. At the end of the experiment, length of the longest lateral shoots, number of lateral shoot and nodes were recorded.

Experiment 3. Effects of light quality and irradiation duration on petunia growth

Twenty-one plants with 6 to 7 true leaves were grown in chamber equipped with MH or HPS. The light intensity was set at 100 μmol·m⁻²·s⁻¹ at the plant canopy under each lamp. In each chamber, the plants were split into three groups, as follows: 1) grown for 45 days under the same light continuously, 2) grown for 15 days under initial lamp and then transferred to another chamber with a different lamp for 30 days, 3) grown for 30 days under the initial lamp and then transferred to another chamber with a different lamp for 15 days. The number of days to flowering and the number of flowers were recorded. On 0, 10, 20, 28, 30, 38, 40 and 45 days after treatment, plant height and canopy diameter were measured. The main stem length, the longest lateral shoot length, and number of lateral shoots and nodes were also recorded.

Experiment 4. Effects of application GA₃ and light quality on petunia growth

Plants were grown for 45 days after transplantation to the growth chamber with MH or HPS set at 100 μmol·m⁻²·s⁻¹ light intensity. At the start of the experiment and 10 days later, each plant was sprayed with 10 ml of 0, 50, 100 ppm GA₃ or 0 ppm Uniconazol (S0-7, Sumitomo Chem. Co. Tokyo, Japan). After 60 days, the plant growth parameters mentioned above in Exp. 3 and number of days to flowering were measured.

Data analysis

In Exp. 1 and 2, five plants were assigned to each lamp treatment. In Exp. 2, treatments of two lamps and three light levels were randomly assigned to chambers with 8 plants, in Exp. 3, treatments of two lamps and three illumination periods were randomly assigned to chambers with 7 plants, and in Exp. 4, treatments of two lamps and three concentrations of GA₃ and Uniconazol treatments were randomly assigned to chambers with 5 plants. Data were subjected to analysis of variance. Differences among treatment means were tested using Tukey-Kramer's test, with P values less than 0.05 are considered statistically significant.

Results

Experiment 1. Effect of light quality on petunia growth

The longest lateral shoot length and average internode length under HPS light was about 30% shorter than that of plants grown under MH and B (Table 2). The number of nodes was similar among the three light qualities. Shoot dry matter weight, number of lateral shoots and stem diameter were similar among three light qualities. The corolla radius and the length of floral tube also showed similar values among the three light qualities.

Table 2. Effect of light quality on the growth of petunia after 45 days of treatment.

<table>
<thead>
<tr>
<th>Light source</th>
<th>Dry matter weight of shoot (g)</th>
<th>Number of lateral shoots (no. plant⁻¹)</th>
<th>Longest lateral shoot length (cm)</th>
<th>Stem diameter (cm)</th>
<th>Number of nodes</th>
<th>Average internode length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MH</td>
<td>5.06 ± 0.28ab⁶</td>
<td>7.5 ± 2.08a</td>
<td>24.9 ± 1.45b</td>
<td>2.91 ± 0.11a</td>
<td>23.0 ± 1.52a</td>
<td>1.09 ± 0.06b</td>
</tr>
<tr>
<td>HPS</td>
<td>5.87 ± 0.39b</td>
<td>8.0 ± 0.45a</td>
<td>17.3 ± 0.39a</td>
<td>2.57 ± 0.11a</td>
<td>21.8 ± 1.20a</td>
<td>0.80 ± 0.04a</td>
</tr>
<tr>
<td>B</td>
<td>4.58 ± 0.20a</td>
<td>5.5 ± 0.77a</td>
<td>24.4 ± 0.77b</td>
<td>2.73 ± 0.13a</td>
<td>21.0 ± 1.05a</td>
<td>1.17 ± 0.05b</td>
</tr>
</tbody>
</table>

⁶ See Table 1.
⁷ Stem diameter was measured at the widest part in the longest lateral shoot on each plant.
⁸ Number of nodes was counted in the longest lateral shoot.
⁹ The longest lateral shoot length / number of nodes.
¹⁰ Mean ± SE (n=5), different letters represent significant differences among different light sources by Tukey-Kramer's test at P=0.05.
(Table 3), but peduncle length in plants grown under HPS was about 30% shorter than that of plants grown under the other two types of lamps. The cell length in the 5th node was affected by the light qualities (Table 4). The length of the cortical and pith cell along the vascular bundle were 11 and 18%, and 21 and 24% shorter under HPS than those under MH and B, respectively.

Experiment 2. Effects of light qualities and light intensities on petunia growth

As light intensity increased, the plant height was proportionately inhibited (Fig. 2) under MH and HPS. Ten days after treatment, the height of plants grown under HPS were already shorter than those of plants grown under MH, regardless of light intensity, and subsequently, remained so.

Plant height under HPS was shorter than that under MH (Table 5), but in both treatments, growth inhibition decreased as the light intensities was decreased. However, as plants grew taller under low light intensity of

Table 3. Effect of light quality on flower morphology of petunia.

<table>
<thead>
<tr>
<th>Light source</th>
<th>Corolla radius (mm)</th>
<th>Floral tube (mm)</th>
<th>Peduncle (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MH</td>
<td>29.3 ± 0.68</td>
<td>39.1 ± 0.55a</td>
<td>29.1 ± 1.33b</td>
</tr>
<tr>
<td>HPS</td>
<td>29.1 ± 0.62</td>
<td>40.8 ± 0.54a</td>
<td>20.1 ± 0.90a</td>
</tr>
<tr>
<td>B</td>
<td>28.8 ± 0.58a</td>
<td>39.7 ± 0.58a</td>
<td>27.7 ± 1.24b</td>
</tr>
</tbody>
</table>

- See Table 1.
- Mean ± SE. Different letters represent significant differences among different light sources by Tukey-Kramer’s test at P=0.05.

Table 4. Effect of light quality on cell length in the 5th internode of stem in petunia after 45 days of treatment.

<table>
<thead>
<tr>
<th>Light source</th>
<th>Cortex (μm)</th>
<th>Pith (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MH</td>
<td>52.5 ± 0.83ab</td>
<td>74.8 ± 2.57ab</td>
</tr>
<tr>
<td>HPS</td>
<td>46.6 ± 1.53a</td>
<td>59.4 ± 4.27a</td>
</tr>
<tr>
<td>B</td>
<td>56.9 ± 2.36b</td>
<td>78.5 ± 3.78b</td>
</tr>
</tbody>
</table>

- See Table 1.
- Mean ± SE (n=9). Different letters represent significant among different light sources by Tukey-Kramer’s test at P=0.05.

Table 5. Effect of light qualities and intensities on the growth of petunia after 45 days of the treatment.

<table>
<thead>
<tr>
<th>Light source</th>
<th>Light intensity (μmol m⁻² s⁻¹)</th>
<th>Plant height (cm)</th>
<th>Plant diameter (cm)</th>
<th>Longest lateral shoot length (cm)</th>
<th>Number of nodes</th>
<th>Average internode length (cm)</th>
<th>Days to flowering</th>
</tr>
</thead>
<tbody>
<tr>
<td>MH</td>
<td>100</td>
<td>29.6 ± 1.30</td>
<td>34.3 ± 1.64</td>
<td>29.4 ± 1.72</td>
<td>17.0 ± 0.89</td>
<td>1.75 ± 0.12</td>
<td>28.6 ± 0.84</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>23.8 ± 1.34</td>
<td>32.5 ± 0.98</td>
<td>24.8 ± 0.49</td>
<td>15.9 ± 0.91</td>
<td>1.61 ± 0.11</td>
<td>27.5 ± 1.21</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>20.6 ± 1.17</td>
<td>33.1 ± 1.48</td>
<td>21.4 ± 1.36</td>
<td>17.6 ± 0.42</td>
<td>1.22 ± 0.08</td>
<td>22.8 ± 1.19</td>
</tr>
<tr>
<td>HPS</td>
<td>100</td>
<td>18.4 ± 1.14</td>
<td>34.3 ± 1.26</td>
<td>19.1 ± 0.95</td>
<td>16.3 ± 1.06</td>
<td>1.21 ± 0.08</td>
<td>35.3 ± 1.08</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>15.6 ± 0.60</td>
<td>32.9 ± 0.98</td>
<td>18.1 ± 0.50</td>
<td>16.1 ± 0.61</td>
<td>1.13 ± 0.06</td>
<td>27.7 ± 0.99</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>13.6 ± 0.46</td>
<td>30.5 ± 1.07</td>
<td>15.1 ± 0.92</td>
<td>15.9 ± 0.40</td>
<td>0.95 ± 0.04</td>
<td>25.7 ± 0.84</td>
</tr>
</tbody>
</table>

- See Table 1.
- Days to flowering show the periods from the starting of the treatment to the first flower opening.
- Mean ± SE (n=8).
- **, *** and NS indicate significance at P=0.01, 0.001 and nonsignificance, respectively.
MH, the growth became more succulent. Especially, as plant height under low light intensity became higher under MH, plant shape seemed to be a plant that showed succulent growth. The longest lateral shoot length and average internode length paralleled that of plant height, whereas plant canopy diameter and number of nodes were unaffected by light qualities and intensities. Under both light sources, as intensities were increased, the flowering dates were delayed.

**Experiment 3. Effects of light quality and irradiation duration on petunia growth**

When petunias were irradiated with MH or HPS for 15 or 30 days during the experiment and then reversed, those under HPS which were moved to MH, began to grow rapidly (Fig. 3A). After 15 days of treatment, plant height under HPS was approximately 60% that of plants under MH, but when transferred from HPS to MH, the elongation rate increased so that after 45 days, they were as tall as plants grown continuously under MH.

When plants were transferred from MH to HPS condition, the growth rate changed (Fig. 3B), i.e., after 15 days under MH, the plants transferred to HPS, the plants grew slowly, such that at the end of the experiment period, those transferred from MH to HPS were 20% lower than those kept under continuous MH.

When plants were transferred from HPS to MH treatment, they attained statures similar to those kept under MH continuously (Table 6). Hence, the final height of the plant transferred from HPS to MH; it was unaffected by the days of exposure to HPS. Main stem length, corresponded similarly to plant height, whereas, plant canopy diameter and number of nodes were unaffected by light quality.

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![Fig. 3. Effects of light quality and duration on the growth of petunia. Arrows show the day of transferring from MH to HPS and HPS to MH, respectively. Legend mean that MH and HPS are light sources and following numbers are lighting period (days).](image)

<table>
<thead>
<tr>
<th>Light source</th>
<th>Lighting period (day)</th>
<th>Plant height (cm)</th>
<th>Plant diameter (cm)</th>
<th>Main stem length (cm)</th>
<th>Longest lateral shoot length (cm)</th>
<th>Number of nodes</th>
<th>Average internode length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MH</td>
<td>0</td>
<td>18.1 ± 0.60b^v</td>
<td>34.5 ± 0.74b</td>
<td>12.8 ± 0.80b</td>
<td>21.7 ± 1.09b</td>
<td>18.3 ± 0.70a</td>
<td>1.20 ± 0.07b</td>
</tr>
<tr>
<td>HPS to MH</td>
<td>15</td>
<td>16.9 ± 1.13b</td>
<td>33.9 ± 0.94ab</td>
<td>11.3 ± 1.26ab</td>
<td>21.3 ± 1.45b</td>
<td>19.1 ± 0.34a</td>
<td>1.12 ± 0.08ab</td>
</tr>
<tr>
<td>HPS to MH</td>
<td>30</td>
<td>16.5 ± 0.69b</td>
<td>31.1 ± 0.97a</td>
<td>12.5 ± 0.76b</td>
<td>19.7 ± 1.70ab</td>
<td>18.7 ± 0.56a</td>
<td>1.06 ± 0.07ab</td>
</tr>
<tr>
<td>HPS</td>
<td>45</td>
<td>12.2 ± 0.46a</td>
<td>33.2 ± 0.95b</td>
<td>8.2 ± 0.36a</td>
<td>15.2 ± 0.56a</td>
<td>17.3 ± 0.82a</td>
<td>0.89 ± 0.03a</td>
</tr>
<tr>
<td>MH</td>
<td>0</td>
<td>18.1 ± 0.60c</td>
<td>34.5 ± 0.74a</td>
<td>12.8 ± 0.08b</td>
<td>21.7 ± 1.09b</td>
<td>18.3 ± 0.70a</td>
<td>1.20 ± 0.07c</td>
</tr>
<tr>
<td>MH to HPS</td>
<td>15</td>
<td>14.8 ± 0.74b</td>
<td>34.9 ± 0.78a</td>
<td>9.7 ± 0.51a</td>
<td>17.1 ± 0.80a</td>
<td>16.2 ± 0.54a</td>
<td>1.06 ± 0.04bc</td>
</tr>
<tr>
<td>MH to HPS</td>
<td>30</td>
<td>13.4 ± 0.74ab</td>
<td>33.0 ± 1.69a</td>
<td>9.3 ± 0.48a</td>
<td>14.5 ± 0.76a</td>
<td>17.4 ± 0.57a</td>
<td>0.83 ± 0.03a</td>
</tr>
<tr>
<td>HPS</td>
<td>45</td>
<td>12.2 ± 0.46a</td>
<td>33.2 ± 0.95a</td>
<td>8.2 ± 0.36a</td>
<td>15.2 ± 0.56a</td>
<td>17.3 ± 0.82a</td>
<td>0.89 ± 0.03ab</td>
</tr>
</tbody>
</table>

^v See Table 1.
^v Lighting period show the number of the days when plants were grown under HPS.
^x See Table 2.
^x See Table 5.
^v Mean ± SE (n=7), different letters represent significant differences among different treatments by Tukey-Kramer's test at P=0.05.
Table 7. Effects of \( \text{GA}_3 \) and Uniconazol applications on growth of petunia under MH or HPS.

| Treatment | Plant height (cm) | No. of lateral shoots (plant) | Main stem length (cm) | Longest lateral shoot length (cm) | Average internode length (cm) | No. of flowers (plant) | Days to flowering
<table>
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<tbody>
<tr>
<td>MH</td>
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<td></td>
</tr>
<tr>
<td>Uniconazol (10)</td>
<td>12.2 ± 0.92</td>
<td>9.0 ± 0.84</td>
<td>5.7 ± 0.36</td>
<td>19.8 ± 0.83</td>
<td>0.82 ± 0.04</td>
<td>79.4 ± 11.1</td>
<td>35.4 ± 0.40</td>
</tr>
<tr>
<td>GA(_3) (0)</td>
<td>17.7 ± 1.27</td>
<td>9.0 ± 0.70</td>
<td>7.8 ± 0.52</td>
<td>22.9 ± 1.57</td>
<td>0.93 ± 0.04</td>
<td>76.0 ± 12.5</td>
<td>34.2 ± 1.20</td>
</tr>
<tr>
<td>GA(_3) (50)</td>
<td>30.2 ± 1.48</td>
<td>7.5 ± 0.65</td>
<td>25.8 ± 2.13</td>
<td>28.8 ± 1.65</td>
<td>1.20 ± 0.07</td>
<td>54.5 ± 3.1</td>
<td>32.4 ± 0.68</td>
</tr>
<tr>
<td>GA(_3) (100)</td>
<td>42.1 ± 1.79</td>
<td>7.0 ± 0.45</td>
<td>38.2 ± 1.42</td>
<td>41.6 ± 1.53</td>
<td>1.69 ± 0.03</td>
<td>59.2 ± 4.9</td>
<td>29.8 ± 0.20</td>
</tr>
<tr>
<td>HPS</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uniconazol (10)</td>
<td>9.9 ± 0.33</td>
<td>11.0 ± 0.84</td>
<td>4.4 ± 0.23</td>
<td>15.2 ± 0.83</td>
<td>0.67 ± 0.04</td>
<td>80.0 ± 5.7</td>
<td>37.6 ± 0.60</td>
</tr>
<tr>
<td>GA(_3) (0)</td>
<td>11.2 ± 0.61</td>
<td>10.0 ± 0.32</td>
<td>4.5 ± 0.31</td>
<td>16.6 ± 1.06</td>
<td>0.70 ± 0.03</td>
<td>87.8 ± 6.0</td>
<td>34.8 ± 0.37</td>
</tr>
<tr>
<td>GA(_3) (50)</td>
<td>25.8 ± 1.13</td>
<td>7.8 ± 0.58</td>
<td>21.7 ± 0.96</td>
<td>21.5 ± 0.72</td>
<td>0.95 ± 0.05</td>
<td>69.4 ± 8.4</td>
<td>31.2 ± 0.58</td>
</tr>
<tr>
<td>GA(_3) (100)</td>
<td>28.7 ± 0.92</td>
<td>9.2 ± 0.58</td>
<td>24.9 ± 0.96</td>
<td>27.0 ± 1.15</td>
<td>1.12 ± 0.04</td>
<td>81.6 ± 6.0</td>
<td>30.6 ± 0.68</td>
</tr>
</tbody>
</table>

Significance:
- Light source (L): ***
- Spray (S): ***
- L × S: NS

\[ \dagger \] See Table 1.
\[ \ddagger \] At the start of experiment and 10 days after treatment, each plant was sprayed with \( \text{GA}_3 \) and Uniconazol.
\[ \star \] See Table 2.
\[ \ddagger \ddagger \] See Table 5.
\[ \ast \] Mean ± SE (n=5).

All data were recorded after 45 days of treatment.

**Experiment 4. Effects of application of \( \text{GA}_3 \) and light quality on petunia growth**

\( \text{GA}_3 \) application increased plant height, and reversed the plant growth suppressed by HPS lamp (Table 7). However, the response to exogenous \( \text{GA}_3 \) differed between MH and HPS. Under MH, the increasing \( \text{GA}_3 \) concentration from 50 to 100 ppm significantly increased plant height. Sixty days after treatment, plant height under MH, \( \text{GA}_3 \) treated ones were 70 and 138%, respectively taller than those treated with water, whereas those under HPS treated with 50 ppm \( \text{GA}_3 \) were 130% taller than the control. However, the 100 ppm \( \text{GA}_3 \) treatment had less effect on the elongation of plant height under HPS. Main stem length, the longest lateral shoot length and average internode length on the longest lateral shoot responded similarly to plant height.

Uniconazol application under MH resulted in a 32% reduction in plant height than that of the water control 60 days after treatment, whereas, Uniconazol had little effect on the plant height under HPS.

Increasing the \( \text{GA}_3 \) concentration tended to decrease the number of lateral shoots and shorten the days to flowering, plants under HPS produced many lateral shoots; there was no difference in the days to anthesis from seedling between MH and HPS.

**Discussion**

Plants grown under HPS were shorter than those grown under MH or B (Table 2), because cell and internode length were also shortened under HPS. We attribute these responses to the HPS lamp that has a spectrum with high R/FR ratio (Table 1). Contrarily, Kasperbauer (1988) found that plants exposed to a low R/FR ratio had short internodes and plant heights. Kubota et al. (2000) reported that petunia became compact and the number of days to flowering was delayed under R-rich spectrum. In a preliminary examination, petunia grew taller when the R/FR ratio of the light of HPS lamp was reduced by means of a light-selective filter (Ubukawa et al., 2001). Bleiss (1994) reported that, the elongation of basal cells of wheat coleoptiles grown in the dark, was inhibited when pulsed by red light. Likewise, the light of HPS inhibited cell elongation of petunia internode.

Shorter and more compact peach plants were produced under blue and FR-rich light (Baraldi et al., 1998). Maas et al. (1995) reported that the increase in internode length of kidney bean under orange light, was caused by the deficiency of blue light.; Appelgren, (1991) demonstrated that stem elongation of *Pelargonium* was inhibited in *vitro* by blue light, whereas elongation of the stem and hypocotyl is suppressed in many species under blue light, it had no effect on the plant height of petunias in this experiment (Table 2). Inada (1984) classified growth responses to light qualities into two groups: a) species in which red light inhibits cell elongation more effectively than blue light; b) species in which the response was reversed. Petunia was classified into the former group (Inada, 1984), which we confirmed.

Petunia plant height was affected by light quality as
well as its intensity. But the effects of light intensity on plant height depended on light qualities. Under low light intensity, plant height and internode length were greater than those under high light intensity. However, while low light intensity had only a marginally affected plant height under HPS, it promoted growth under MH. Generally, plants grow tall but weakly when they are in the shade of other plants or when they receive only low light intensity (etiolation). Kasperbauer (1988) attributed that the responses to the canopy which acts as a selective filter that absorbs red and blue is relatively transparent to FR. Under low light intensities of MH or HPS, petunia put on succulent growth but the degree of succulence was less under HPS than under MH.

Petunia responded so rapidly to the light quality changes such that plant height was altered within 10 days of change. Bleiss and Smith (1985) found that change in dark-grown coleoptile length was detectable within 8 to 10 min. after being irradiated with red light. However, mechanism of inhibition under R-rich light may be similar between our study on dwarf; petunia and wheat coleoptiles of Bleiss and Smith (1985). Rapid response to the modulation of light quality is governed by phytochrome, which alters the course of cell elongation. Petunia grows continuously without the effect of flowering. It can be presumed that elongation of the young internode could respond to the change of light quality. Therefore, there is no resident effect of light quality on plant growth in petunia.

Plant shape under HPS, became compact, developing many lateral shoots, but delaying anthesis, mimicking the growth pattern of plants treated with Uniconazol which inhibits the GA biosynthesis (Table 7). Rajapakse and Kelly (1992) reported that application of GA₃ alone before irradiation partially overcome the height reduction of chrysanthemums under CuSO₄ filters which indicates that GA biosynthesis and/or action may be affected by light quality. In dwarf petunia, growth inhibition under a high R/FR light regimen was also reversed by application of GA₃, while Uniconazol was ineffective. Uniconazol which inhibits the GA biosynthesis in plants (Kamiya, 1991) induces photomorphogenic responses mediated by the phytochrome system (Chory and Li, 1997). Our results from exposing petunia to high R/FR ratio may have induced a low GA concentration which prevented shoot elongation. Hence, the stem elongation responded quickly when plants were transferred from MH to HPS or from HPS to MH. Toyomasu et al. (1993) reported that in seeds of lettuce cv. Grand Rapids, endogenous GA₁ concentration increased after a brief red light irradiation, and that far-red light given after red light negated it. Seeds and leaves may not have the same GA biosynthesis system, but because growth inhibition of petunia irradiated with high R/FR ratio was reversible by GA or by transferring to the MH treatment, the response indicate that GA biosynthesis and light effects are interrelated.

Literature Cited


Toyomasu, T., H. Tsuji, H. Yamane and M. Nakayama. I.
数種人工光源の光質、光強度ならびに光照射期間がペチュニアの生育に及ぼす影響

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数種人工光源の光質がペチュニアの生育に及ぼす影響について、光強度、照射期間などの関係する要因とともに評価した。環境制御室に設置したメタルハライドランプ（MH）、高圧ナトリウムランプ（HPS）および青色光ランプ（B）下でわい性中輪咲ペチュニア「パラブルー」を栽培し、生育の比較を行った。実験では、光質、光強度および照射期間などの光環境要因を、各要因との相互作用が生育に及ぼす影響を調査した。さらに、GA3およびウニコナゾール処理を行い、光質がペチュニアの生育に及ぼす影響をジベレリンとの関連について考察した。

1. MHやB下に比べて、HPS下で栽培したペチュニアは、草姿がわび化する傾向があった。HPS下の最大側枝長はMHやB下よりも約30%わび化し、間節長も短くなった。HPS下において草姿がわび化したのは、HPSの赤色/青色光比（R/FR）が高かったことから、フィトクロム反応が原因であると考えられる。

2. MHおよびHPSの両光源下では、光強度が低いほど草丈が高くなった。しかし、いずれの光強度においても、HPS下で生育した植物の草丈はMHよりも低かった。

3. 生育期間中に植物をMHからHPS下に移動したところ、草丈の伸長速度が低下した。このことから、ペチュニアの草丈は生育後半に受けた光質の影響を大きく受けることが、ならびにペチュニアの草丈に及ぼす人工光源の光質の影響には残効性がないことが示された。

4. HPS下の植物体ではGA3処理により草丈の著しい増加が認められたが、ウニコナゾール処理による茎伸長抑制効果はほとんど観察されなかった。以上のことから、R/FRが高い光環境下では、内生ジベレリン濃度が低下し、その結果として草丈が短くなる可能性が示唆された。

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