Effects of Red and Far-red Fluororescent Light on the Growth of Gypsophila paniculata Plants

著者	Katsuta Keiko, Moriyama Takayoshi, Nishiyama Manabu, Kanayama Yoshihiro, Kanahama Koki
journal or publication title	Tohoku journal of agricultural research
volume	59
number	1-2
page range	1-16
year	2008-11
URL	http://hdl.handle.net/10097/44363

Tohoku Journal of Agricultural Research
Vol. 59 No. 1-2, November 2008
Printed in Japan

Effects of Red and Far-red Fluorescent Light on the Growth of *Gypsophila paniculata* Plants

Keiko KATSUTA[1], Takayoshi MORIYAMA[2], Manabu NISHIYAMA[1], Yoshinori KANAYAMA[1] and Koki KANAHAMA[1]

[1]*Laboratory of Horticultural Science, Graduate School of Agricultural Science, Tohoku University, Sendai 981-8555, Japan*
[2]*Toshiba Lighting & Technology Corporation, Funakoshi, Yokosuka 237-8510, Japan*

(Received, October 1, 2008)

Summary

The effects of red and far-red irradiation on the growth and flowering of *Gypsophila paniculata* L. plants were investigated. In the first experiment, plants were grown in phytotrons maintained at day (6 : 00-18 : 00)/night (18 : 00-6 : 00) temperatures of 17/12°C, 24/19°C, or 30/25°C under a 24-hr photoperiod with 8-hr of natural daylight and 16-hr of artificial lighting with incandescent lamps, far-red fluorescent lamps, or red fluorescent lamps. The plant height was greater and number of days to flowering was less in the case of plants grown under the far-red fluorescent lamp than in those grown under the red fluorescent lamp. Although far-red light accelerated flowering to a greater extent at high temperature (30/25°C) than at low temperature (17/12°C), the quality of the cut flowers was best at low temperature. In the second experiment, the effects of the intensity of far-red fluorescent light were investigated. Plants were grown at day/night temperatures of 17/12°C, 24/19°C, or 30/25°C under a 24-hr photoperiod with 8-hr of natural daylight and 16-hr of artificial lighting with 1, 2, or 4 far-red fluorescent lamps. Far-red light at a high intensity accelerated the increase in plant height and reduced the number of days to flowering, irrespective of temperature. It is expected that high-quality cut flowers can be obtained by cultivating the plants under overnight irradiation with intense far-red light at a low temperature of 17/12°C, although the number of days to flowering is less at high temperature of 30/25°C.

In the first experiment, we observed that the number of days to flowering was less in the case of plants grown under the incandescent lamp than those grown under the far-red fluorescent lamp, irrespective of temperature; this is because the intensity of light from incandescent lamps was stronger than that of light from fluorescent lamps. In the second experiment, the number of days to flowering was identical in the case of the plants grown under 4 fluorescent lamps and those under an incandescent lamp. However, considering the energy exchange efficiency and long life of far-red fluorescent lamps, it is expected that these lamps are a more effective light source.

Key words: far-red light, *Gypsophila paniculata* L., light quality, red light, temperature

The flowers of the long-day plant *Gypsophila paniculata* L. are one of the major cut flowers in Japan, and they are in demand throughout the year; they can be used in bouquets, flower arrangements, and so on. To meet this demand, these plants are cultivated in the warm southwest and central regions of the country where shipping is from fall to the next spring and in cool regions where shipping is from summer to fall. Forcing culture is a major cultivation method in the southwest region. In this method, cuttings are planted in July; because of the high temperature in summer, the plants are induced in the physiological rosette stage, and because of the subsequent low light intensity, low temperature, and short days in fall, they are induced in the morphological rosette stage (Doi *et al.*, 1991; Suto *et al.*, 1987). Therefore, heat and light (long-day treatment) are necessary to prevent induction of the rosette stage. Incandescent lamps are usually used as light sources; however, the efficiency with which they convert electric energy to light energy is low, and they generate heat. For energy and environmental conservation, the use of incandescent lamps is being avoided worldwide, and an alternative light source is required. The effects of fluorescent lamps on *G. paniculata* have been discussed previously. Lighting with cool-white fluorescent lamps, which produce light with a high red to far-red (R/FR) ratio, did not induce flowering, and the plants remained vegetative in the rosette stage (Shillo and Halevy, 1982). Similar results were reported in studies conducted by Zande and Blacquière (1997). In contrast, incandescent lamps, which produce light with low R/FR ratio, induced flowering, and it was concluded that the far-red light emitted by incandescent lamps is effective in inducing flowering (Kadman-Zahavi and Gartenhause, 1989; Zande and Blacquière, 1997). It is well known that the R/FR ratio affects plant growth (Smith, 1998). It appears that the growth of *G. paniculata* can be controlled by the use of red or far-red light. In the present study, fluorescent light bulbs that produce red or far-red light and consume lower energy than incandescent lamps were experimentally manufactured and compared with incandescent lamps.

Materials and Methods

Plant Material

G. paniculata L. 'Bristol Fairy' was used in the experiments. The plants were obtained from a commercial nursery (Daiichi Engei Ltd.). They were individually potted in a clay pot (diameter, 15 cm) on April 18, 2001 (Exp. 1) and April 19, 2002 (Exp. 2). Ten plants were included in each treatment group in Exp. 1, and 9 plants were included in each treatment group in Exp. 2. Thinning was performed to obtain 3 shoots per plant. The number of tested shoots is shown in Tables 1 (Exp. 1) and 3 (Exp. 2).

Light Sources

An incandescent lamp (abbreviated as W) (100 W ; Toshiba Lighting and Technology Corp.), a far-red fluorescent light bulb (abbreviated as FR) (prototype ; Toshiba Lighting and Technology Corp.), and a red fluorescent light bulb (abbreviated as R) (prototype ; Toshiba Lighting and Technology Corp.) were used in this study. The spectral distributions of these lamps are shown in Fig. 1. We used 14 W and 21 W fluorescent lamps in Exp. 1 and Exp. 2, respectively, though the spectral distributions of these lamps were the same.

Treatment at Different Temperatures and Photoperiods

Experiments were conducted at the Graduate School of Agricultural Science, Tohoku University, Japan, and 3 natural-light phytotrons were used. The temperature of these phytotrons was set at 17/12°C, 24/19°C, and 30/25°C (day : 6 : 00–18 : 00/night : 18 : 00–6 : 00). The plants were placed in frames set in the phytotrons and grown under natural daylight from 9 : 00 to 17 : 00. The frames were covered with double-layered silver polyethylene films from 17 : 00 to 9 : 00 on the following day in order to shade the plants from outside light. While the plants were shaded, they were irradiated with the abovementioned light sources. A 24-hr photoperiod comprising 8-hr of natural daylight and 16-hr of artificial lighting was maintained during each treatment, except for an 8-hr photoperiod treatment used as the control in Exp. 2., where the plants were provided natural daylight only.

Exp. 1. Effects of R and FR Fluorescent Light

Nine different types of treatment conditions were set up by combining the 3 different temperature conditions (17/12°C, 24/19°C, and 30/25°C) with the 3 light sources (W, FR, and R).

Each lamp was set in a frame (depth, 105 cm ; width, 70 cm ; height, 115 cm) at a distance of 90 cm from the floor. The average irradiance of W, FR, and R on the floor just below the light sources was 2.49 ± 0.05, 0.29 ± 0.05, and 0.24 ± 0.01 W/m^2, respectively.

The experiment was started on May 14, 2001, and terminated after 20 weeks, i.e., on October 2, 2001.

Exp. 2. Effect of FR light intensity

Nine different treatment conditions were set up by combining the 3 temperature conditions (17/12°C, 24/19°C, and 30/25°C) with 3 FR light intensity levels achieved using FR lamps with 1, 2, or 4 bulbs (represented as 1FR, 2FR, and 4FR,

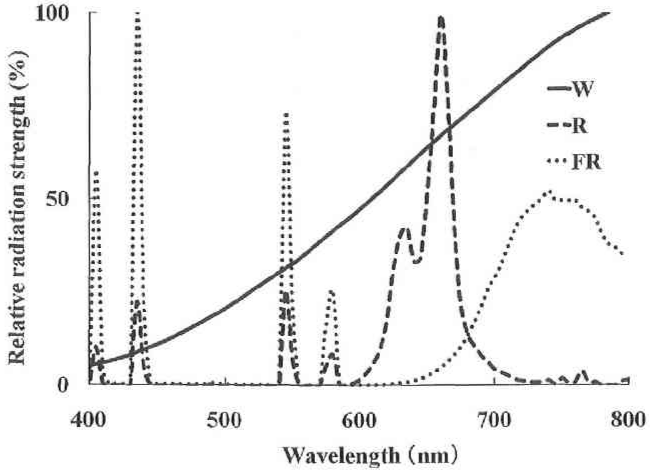

FIG. 1. Spectral distributions of light produced by the incandescent lamp and the red and far-red fluorescent light.

respectively, in this study). In addition, an 8-hr photoperiod treatment and W-treatment conditions were set up at 24/19°C; therefore, this experiment included 11 treatment conditions.

The lamps were set in frames (depth, 80 cm; width, 76 cm; height, 113–160 cm) at a distance of 90 cm from the floor. In the 17/12°C condition, the lamps were raised corresponding to the increase in plant height. The average irradiance of W, 1FR, 2FR, and 4FR measured at 9 points on the floor was 2.49 ± 0.05, 0.29 ± 0.01, 0.50 ± 0.02, and 1.00 ± 0.03 W/m^2, respectively.

The experiment was started on May 16, 2002, and terminated after 20 weeks, i.e., on October 9, 2002.

Assessment Methods

The same assessment methods were used in Exp. 1 and Exp. 2. The number of expanded leaves on the main shoot was counted every week. Plant height, which is the length from the ground to the uppermost node, was measured every week. Since the leaves of *Gypsophila* are opposite, the node number was calculated by dividing the number of expanded leaves by 2. The average internode length was calculated by dividing the plant height by the number of nodes. The flowering shoots were harvested within 4–7 days after flower opening and used to investigate the quality of cut flowers. The parameters investigated included cut-flower length, fresh weight, and stem diameter. Moreover, the highest floret branch orders in the inflorescence units was also investigated as described by Hayashi *et al.* (1992).

Results

Exp. 1. Effects of R and FR

The flowering shoots were the longest in plants grown in FR light, followed by W and R light (Table 1). This tendency was observed irrespective of the temperature. The flowering shoots began elongating earliest in plants grown in W light, followed by FR and R light (Fig. 2). Internode lengths were the longest in plants grown in W light, followed by FR and R light (Table 1). The number of days to flowering from the start of the experiment was the shortest in the case of W light, followed by FR and R light (Table 1). The flowering period was

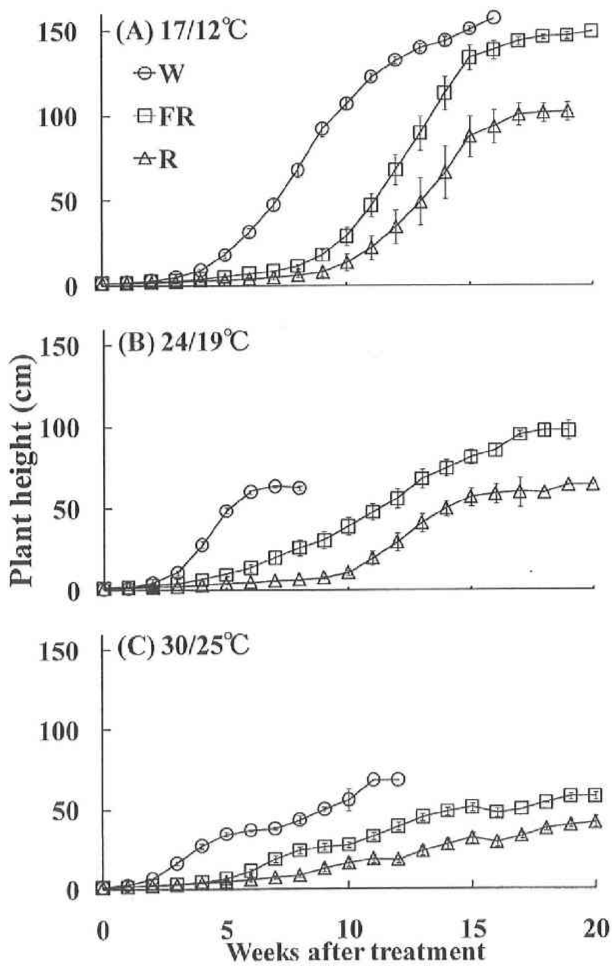

FIG. 2. Effects of red and far-red fluorescent light on the height of *Gypsophila paniculata* plants. Data were collected using flowering shoots. The vertical bars represent standard errors.

Table 1. Effects of red and far-red fluorescent light on the growth of Gypsophila paniculata plants[a]

Day/night temperature (°C)	Light source[b]	Number of shoots tested[c]	Number of flowering shoots	Number of days to flowering[d]	Flowering shoot			Nonflowering shoot		
					Plant height (cm)	Number of leaves	Internode length (cm)[e]	Plant height (cm)	Number of leaves	Internode length (cm)[e]
17/12	W	30	30	89.7±1.9[f]	135.8±2.2	60.1±1.2	4.5±0.0	—	—	—
	FR	29	5	127.6±3.4	146.4±1.6	73.2±1.6	4.0±0.1	53.4±10.1	71.2±2.1	1.4±0.2
	R	30	2	132.0±1.0	102.3±5.7	69.0±1.0	3.0±0.2	23.6±6.0	64.0±1.6	0.7±0.1
24/19	W	30	30	45.4±0.8	62.3±0.8	46.9±0.4	2.7±0.0	—	—	—
	FR	30	21	99.1±4.7	89.6±1.9	79.2±2.1	2.3±0.0	53.5±5.8	97.6±3.6	1.1±0.1
	R	29	9	107.9±4.6	62.3±1.4	82.4±2.7	1.5±0.0	25.9±2.3	95.7±0.8	0.5±0.0
30/25	W	30	30	46.1±1.7	39.9±1.1	43.6±1.0	1.8±0.0	—	—	—
	FR	30	25	84.9±5.4	45.6±2.0	65.0±2.5	1.4±0.0	31.4±5.9	75.2±4.1	0.8±0.1
	R	28	13	101.2±7.6	35.4±2.0	77.2±4.4	0.9±0.0	22.0±1.3	90.0±1.6	0.5±0.0

[a] Data regarding the flowering shoots were obtained on the day of flowering, and data regarding the nonflowering shoots were obtained at the end of treatment (20 weeks after the beginning of treatment).
[b] W: Incandescent lamp (100 W). FR: Far-red fluorescent lamp (14 W). R: Red fluorescent lamp (14 W).
[c] Thinning was performed to obtain 3 shoots per plant, and 10 plants were used in each treatment group. Therefore, there were 30 shoots in each treatment group. However, under some treatment conditions, 1 or 2 shoots did not grow completely.
[d] Number of days to flowering from the start of treatment.
[e] Plant height/Number of nodes.
[f] Mean±SE.

shortest in the case of plants grown in W light; longer periods were observed in the case of plants grown in FR and R light (Fig. 2). The percentage of flowering shoots was the highest in the case of plants grown in W light, followed by FR and R light (Fig. 3). The percentage of flowering shoots in the case of plants grown in W light reached 100%, irrespective of the temperature; however, the percentage of flowering shoots never reached 100% in the case of plants grown in R light, irrespective of the temperature.

On comparing the effects of temperature, we found that both shoot and internode lengths were the longest in plants grown at 17/12°C, followed by 24/19°C and 30/25°C, irrespective of the light source (Table 1). The increase in leaf

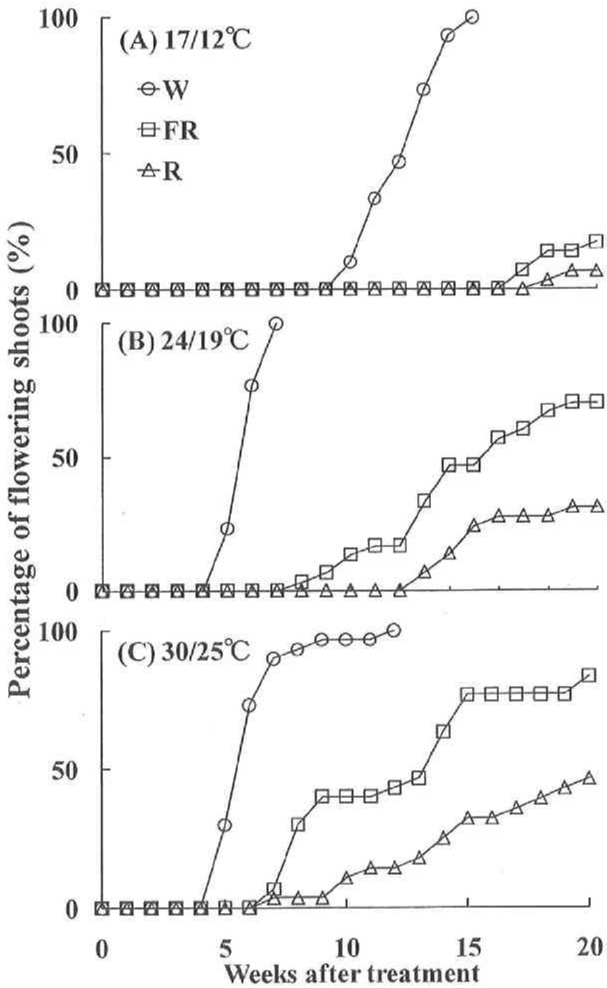

FIG. 3. Effects of red and far-red fluorescent light on the percentage of flowering shoots in the case of the *Gypsophila paniculata* plants.

Table 2. Effects of red and far-red fluorescenct light on the quality of cut flowers

Day/night temperature (°C)	Light source[a]	Length (cm)	Fresh weight (g)	Stem diameter (mm)	Highest floret branch orders
17/12	W	129.8±2.1[b]	32.6±0.7	3.5±0.1	5.1±0.1
	FR	135.7±1.7	48.8±1.8	5.0±0.1	4.2±0.2
	R	96.5±5.8	29.9±1.9	4.4±0.1	4.5±0.5
24/19	W	56.2±0.8	7.8±0.3	2.6±0.1	5.0±0.1
	FR	84.3±1.9	20.9±0.6	2.9±0.1	4.4±0.2
	R	56.6±1.4	27.2±1.3	3.1±0.1	4.8±0.2
30/25	W	33.7±1.2	5.2±0.4	1.8±0.1	3.9±0.1
	FR	39.8±2.0	7.7±0.5	1.9±0.0	3.4±0.1
	R	29.7±2.0	12.9±1.2	2.5±0.1	3.5±0.3

[a] For the 3 abbreviations (W, FR, and R), please refer to Table 1.
[b] Mean±SE.

number was slow at 17/12°C (data not shown). The number of days to flowering from the start of the experiment was the least in the case of plants grown at 30/25°C, and it was higher at 24/19°C and the highest at 17/12°C. The effects of the light sources on the plant height and flowering were more apparent at low temperatures than that at high temperatures (Table 1).

With regard to the quality of the cut flowers, the number of floret branch orders was the highest in plants grown in W light followed by FR and R light (Table 2). The cut flowers were the longest in plants grown in FR light and the shortest in the case of those grown in R light. The effects of light quality on the fresh weight and the stem diameter were not obvious. A comparison among the plants grown at different temperatures showed that the number of floret branch orders and the lengths of the cut flowers decreased as the temperature increased. The fresh weights of the cut flowers were the highest in the case of plants grown at 17/12°C, followed by 24/19°C and 30/25°C. The stem diameters were the greatest in plants grown at 17/12°C, followed by 24/19°C and 30/25°C. In the case of plants grown in FR light, at 17/12°C, the fresh weight and stem diameter were particularly high. Malformed florets were observed at a high rate in plants grown at 30/25°C, irrespective of the light source (data not shown). We found that the quality of cut flowers is constant in the case of plants grown in FR light, irrespective of the temperature.

Exp. 2. Effects of FR light intensity

Our results showed that in plants grown at 24/19°C under the 8-hr photoperiod, the shoot was very short (Fig. 4) and flowering did not occur (Table 3). These results indicate that *G. paniculata* is a qualitative long-day plant.

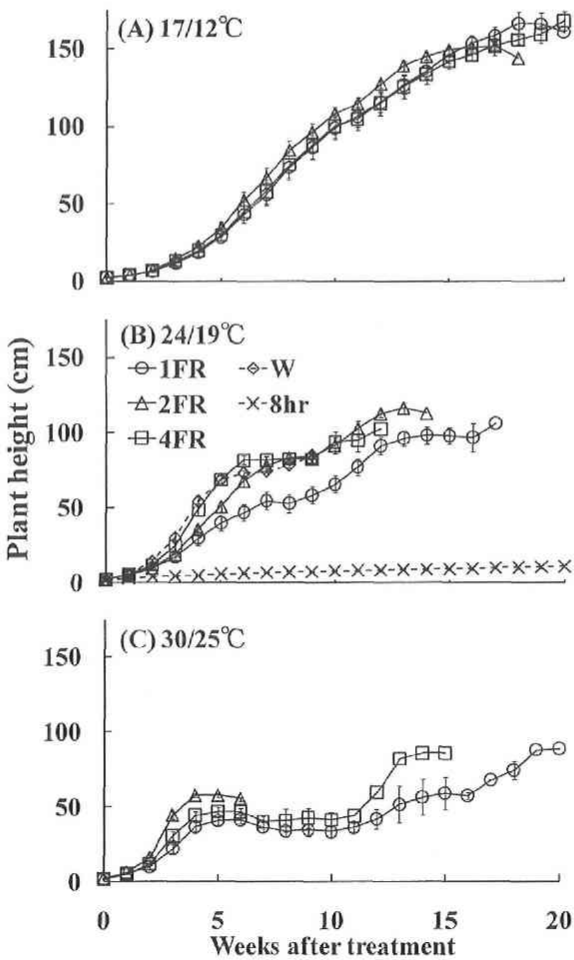

FIG. 4. Effects of far-red light intensity on the height of *Gypsophila paniculata* plants. Data were collected using flowering shoots. The vertical bars represent standard errors.

Comparison among light intensities showed that the number of days to flowering was the lowest in the case of plants grown under 4FR, followed by 2FR and 1FR, irrespective of the temperature (Table 3). Moreover, with an increase in the intensity of far-red light, the number of flowering shoots increased in a short period, irrespective of the temperature (Fig. 5). Plants grown under 4FR had the fewest leaves ; these plants also exhibited the fastest flowering, followed by those grown under 2FR and 1FR. The internode length was the greatest in plants grown under 4FR and the least in those grown under 1FR, although the difference was not great (Table 3). The differences in the plant height corresponded with the increase in the leaf number and internode length (Table 3). The flowering

Table 3. Effects of far-red light intensity on the growth of Gypsophila paniculata plants[a]

Day/night temperature (°C)	Light source[b]	Number of shoots tested[c]	Number of flowering shoots	Number of days to flowering[d]	Flowering shoot			Nonflowering shoot		
					Plant height (cm)	Number of leaves	Internode length (cm)[e]	Plant height (cm)	Number of leaves	Internode length (cm)[e]
17/12	1FR	27	18	102.1±5.0[f]	146.1±4.2	63.9±2.5	4.6±0.1	78.9±14.8	72.9±2.7	2.1±0.3
	2FR	27	22	102.1±5.4	148.4±3.0	63.4±2.4	4.8±0.1	141.0±19.8	79.2±3.4	3.5±0.4
	4FR	27	26	93.3±3.4	139.8±2.5	59.8±1.7	4.7±0.1	178.2	86.0	4.1
24/19	1FR	27	27	72.1±4.6	95.1±1.9	67.9±2.9	2.9±0.1	—	—	—
	2FR	26	26	60.2±2.6	92.6±2.1	56.6±1.7	3.3±0.0	—	—	—
	4FR	27	27	48.1±1.8	88.1±1.0	51.9±1.0	3.4±0.1	—	—	—
	W	27	27	42.9±1.4	77.5±0.9	48.3±0.7	3.2±0.1	—	—	—
	8-hr	27	0	—	—	—	—	10.9±1.0	74.8±2.4	0.3±0.0
30/25	1FR	27	25	53.2±5.6	52.2±2.4	53.0±3.1	2.0±0.1	69.9±17.7	94.0±8.0	1.5±0.3
	2FR	27	27	41.7±2.8	52.7±1.6	45.9±1.5	2.3±0.1	—	—	—
	4FR	27	27	33.9±0.6	58.2±1.1	43.5±0.4	2.7±0.0	—	—	—

[a] Data regarding the flowering shoots were obtained on the day regarding the flowering, and data of nonflowering shoots were obtained on the day at the end of treatment (20 weeks after the beginning of treatment).

[b] 1FR : 1 far-red fluorescent lamp (21 W). 2FR : 2 far-red fluorescent lamps. 4FR : 4 far-red fluorescent lamps. W : incandescent lamp (100 W). 8-hr : Only natural lighting (8-hr photoperiod of daylight).

[c] Thinning was performed to obtain 3 shoots per plant, and 9 plants were used in each treatment. Therefore, there were 27 shoots in each treatment group. However, 1 shoot did not grow completely at 24/19°C under 2FR.

[d] Days to flowering from start of treatment.

[e] Plant height/Number of nodes.

[f] Mean±SE.

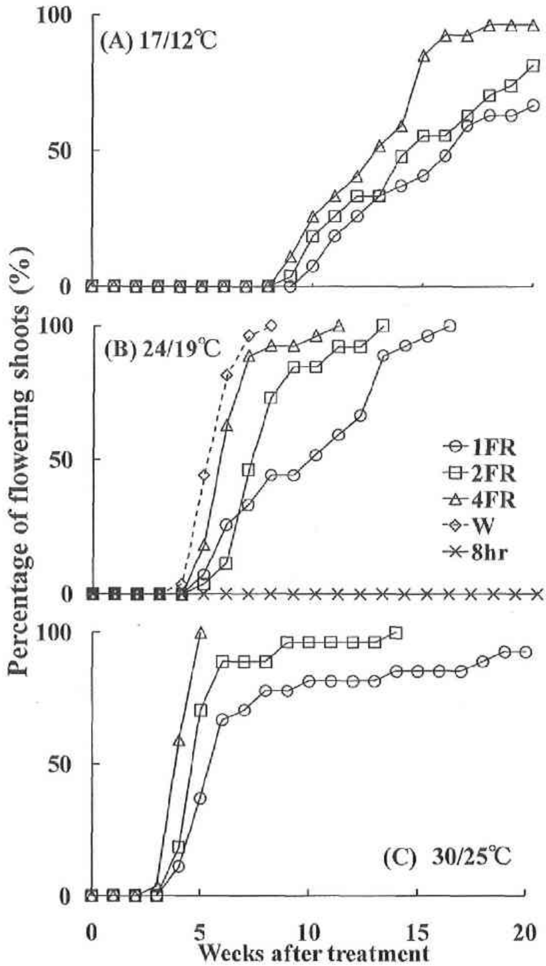

FIG. 5. Effects of far-red light intensity on the percentage of flowering shoots in the case of the *Gypsophila paniculata* plants.

shoots of the plants grown under high FR irradiation were slightly longer; temperature affected the plant height to a greater extent than the intensity of FR irradiation did (Fig. 4). The number of days to flowering was the least in the case of plants grown at 30/25°C, irrespective of the FR intensity; it was higher in the case of plants grown at 24/19°C and the highest in the case of those grown at 17/12°C (Table 3). The height and internode length were the greatest at 17/12°C, followed by 24/19°C and 30/25°C. To determine the quality of the cut flowers, flowering shoots longer than 100 cm were cut to a length of 100 cm and investigated. Comparison among the light intensities revealed that the values of all the assessed parameters were slightly greater and the quality of the cut flowers was substantially better in the case of the plants grown at 30/25°C under 4FR than

Table 4. Effects of far-red intensity on the quality of cut flowers[a]

Day/night temperature (°C)	Light source[b]	Length (cm)	Fresh weight (g)	Stem diameter (mm)	Highest floret branch orders
17/12	1FR	100.0±0.0[c]	19.6±1.7	3.1±0.1	4.4±0.1
	2FR	100.0±0.0	20.0±1.0	3.2±0.1	4.3±0.2
	4FR	100.0±0.0	17.4±1.0	3.0±0.1	4.4±0.1
24/19	1FR	88.3±1.6	13.8±0.6	2.6±0.1	4.2±0.1
	2FR	85.5±1.6	11.2±0.4	2.6±0.1	4.1±0.1
	4FR	82.4±1.0	12.6±0.4	3.0±0.1	4.2±0.2
	W	71.7±0.9	10.5±0.4	2.8±0.1	4.5±0.1
30/25	1FR	46.1±2.4	7.2±0.4	2.3±0.1	3.1±0.2
	2FR	46.7±1.7	7.5±0.5	2.4±0.1	3.9±0.2
	4FR	52.2±1.1	10.0±0.5	2.8±0.1	4.8±0.1

[a] When the length of the cut flowers exceeded 100 cm, the length was adjusted to 100 cm for measurement.

[b] For the 4 abbreviations (1FR, 2FR, 4FR, and W), please refer to Table 3.

[c] Mean±SE.

2FR or 1FR, although no obvious differences were observed in the case of plants grown in FR light at 17/12°C or 24/19°C (Table 4). The cut flowers were the longest in the case of plants grown at 17/12°C, followed by 24/19°C and 30/25°C. The fresh weights of the cut flowers were the highest in the case of plants grown at 17/12°C, followed by 24/19°C and 30/25°C. The effects of temperature on the stem diameter were not obvious.

Discussion

The results of Exp. 1 showed that FR light promoted the growth of *G. paniculata* ; the plant height was greater and flowering began earlier compared to plants grown in R light. Although red light or light with high R/FR ratio promotes flowering in some long-day plants such as *Nigella damascena* (Zimmer, 1988) and spinach (Hamamoto *et al.*, 2004), it is known that far-red light or light with low R/FR ratio promotes flowering in many long-day plants such as *Arabidopsis thaliana* (Bagnall, 1993 ; Eskins, 1992), stock (Yoshimura *et al.*, 2002), petunia (Cathey and Campbell, 1975 ; Lane *et al.*, 1965), *Chrysanthemum frutescens* (Cathey and Campbell, 1975), and others (Friend, 1968 ; Imhoff *et al.*, 1979 ; Lane *et al.*, 1965). *G. paniculata* flowering was also shown to be accelerated under light with low R/FR ratio (Kadman-Zahavi and Gartenhause, 1989 ; Shillo and Halevy, 1982 ; Zande and Blacquière, 1997) ; this result is consistent with that observed in our experiment. It is known that stem elongation in plants is accelerated under light with low R/FR ratio and this phenomenon is called "shade avoidance" (Smith, 1998). Therefore, the increase in the height of *G. paniculata* plants grown under FR may be a typical case of shade avoidance.

With regard to the effect of temperature, the number of days to flowering from the start of the experiment was the least in the case of plants grown at 30/25°C ; it was higher in the case of plants grown at 24/19°C and the highest in the case of those grown at 17/12°C. Similar results were reported by Kusey *et al.* (1981) and Suto *et al.* (1987). Previous studies have shown that the number of days to visible bud appearance was the least in the case of plants grown at 22°C and greatest in the case of those grown at 13°C under 14-, 16-, or 18-hr photoperiods (Kusey *et al.*, 1981) ; further, the number of days to flowering was shown to be the least in the case of plants grown at 30/22°C and the greatest in the case of those grown at 15/7°C under 12-, 14-, or 16-hr photoperiods (Suto *et al.*, 1987). It was also reported that the percentage of blooming plants was the highest among plants grown at high temperature of 27/22°C (Shillo and Halevy, 1982). From these results, it can be concluded that the flowering of *G. paniculata* is accelerated at a high temperature of up to 30/25°C. The effect of temperature on the stem length, shoot length, inflorescence length, or the sum of the shoot and inflorescent lengths of plants grown in the same photoperiod (12-, 14-, 16-, or 18-hr) is not constant (Kusey *et al.*, 1981 ; Suto *et al.*, 1987). In this experiment, the plants were grown under a 24-hr photoperiod and the plant height was found to be the greatest in the case of plants grown at low temperatures, irrespective of the light quality. It is expected that the effects of temperature on the plant height appeared distinctly under the longer photoperiod like this experiment. Although responses to high temperature were different among cultivars and lines, *G. paniculata* vegetative shoots exposed to 30/25°C were induced to formation of rosettes (Doi *et al.*, 1991). In this experiment, however, the heights of the plants grown at 30/25°C were elongated irrespective of the light quality. This was because a 24-hr photoperiod prevented plants from inducing rosette formation. As indicated above, FR light has a more favorable effect than R light on *G. paniculata* growth. However, overnight irradiation with 14W far-red fluorescent lamp, as in the case of this experiment, was less effective than that with a single 100 W white incandescent lamp ; flowering was delayed in the case of the plants grown in FR light compared to those grown in W light, and the rate at which the percentage of flowering shoots increased was slower in the former case than in the latter. These results indicate that the FR intensity probably affects the flowering of *G. paniculata*. Therefore, we conducted Exp. 2 to investigate the effect of the FR light intensity on the growth of *G. paniculata*.

In Exp. 2, we observed that the flowering of *G. paniculata* was affected by the intensity of light, and it was promoted in intense FR light. With regard to the effect of light intensity on the flowering of long-day plants, it is known that bolting begins sooner in *Arabidopsis* plants grown under high-intensity red light irradiation than in those grown under low-intensity irradiation (Eskins, 1992). It is also known that flowering begins soon in petunia plants grown under high-intensity irradiation provided by either metal halide lamps (R/FR=1.1) or high-pressure sodium lamps (R/FR=2.9) (Fukuda *et al.*, 2002).

In the case of plants grown at 24/19°C under an 8-hr photoperiod, the shoot was very short and flowering did not occur. These results indicate that *G. paniculata* is a qualitative long-day plant. Moreover, they correspond with the fact that *G. paniculata* continued vegetative growth and did not flower when grown under the 8-hr photoperiod at any of the tested temperatures (17/12°C, 22/17°C, or 27/22°C) (Shillo and Halevy, 1982).

In this study, the use of 4 21 W FR lamps promoted the flowering of *G. paniculata* without affecting the quality of the cut flowers, and this effect was equivalent to that of a single 100W incandescent lamp. The fluorescent lamps are advantageous in that they consume less electricity, they have a higher light-exchange efficiency than white incandescent lamps, and they last longer. Moreover, the FR fluorescent light bulbs used in this experiment can be set in greenhouses in the same manner as incandescent lamps, and setting up is therefore easy. For these reasons, the FR fluorescent light may be suitable for *G. paniculata* cultivation, particularly under low-temperature and short-day conditions. With regard to the number of light sources, 4 21 W FR fluorescent bulbs were required to obtain an effect equivalent to that of a single 100 W white incandescent lamp. It was previously shown that only far-red light is less effective than incandescent lamps or a combination of red and far-red light, and studies concluded that a combination of red and far-red light of wavelength 500–750 nm is effective in promoting bolting or flowering of *G. paniculata* (Kadman-Zahavi and Gartenhause, 1989; Shillo and Halevy, 1982; Zande and Blacquière, 1997). It is therefore necessary to develop far-red fluorescent lamps that produce light of greater intensity or more effective lighting methods such as those combining red and far-red light.

References

Bagnall, D.J., Light quality and vernalization interact in controlling late flowering in *Arabidopsis* ecotype and mutants. *Ann. Bot.*, **71**, 75–83 (1993).

Cathey, H.M., Campbell, L.E., Effectiveness of five vision-lighting sources on photo-regulation of 22 species of ornamental plants. *J. Amer. Soc. Hort. Sci.*, **100**, 65–71 (1975).

Doi, M., Morishita, T., Takeda, Y., Asahira, T., Effect of exposure to high temperature at different developmental stages of shoots on rosette formation and flower malformation of *Gypsophila paniculata* L. *J. Japan. Soc. Hort. Sci.*, **59**, 795–801 (1991) (In Japanese, with English summary).

Eskins, K., Light-quality effects on *Arabidopsis* development: Red, blue and far-red regulation of flowering and morphology. *Pysiol. Plant.*, **86**, 439-444 (1992).

Friend, D.J.C., Photoperiodic responses of *Brassica. campestris* cv. Ceres. *Pysiol. Plant.*, **21**, 990-1002 (1968).

Fukuda, N., Kobayashi-Yoshinaka, M., Ubukawa, M., Takayanagi, K., Sase, S., Effects of light quality, intensity and duration from different artificial light sources on the growth of petunia (*Petunia* × *hybrida* Vilm.). *J. Japan. Soc. Hort. Sci.*, **71**, 509-516 (2002).

Hamamoto, H., Shimaji, H., Higashide, T., Earlier-bolting spinach cultivars respond to a wider spectrum of night-break light for bolting than later-bolting cultivars. *J. Agric. Meteorol.*, **60**, 191-195 (2004).

Hayashi, T., Miyata, H., Konishi, K., Inflorescence development and composition of *Gypsophila paniculata* L. 'Bristol Fairy'. *J. Japan. Soc. Hort. Sci.*, **61**, 135-141 (1992) (In Japanese, with English summary).

Imhoff, C., Lecharny, A., Jacques, R., Brulfert, J., Two phytochrome-dependent process in *Anagallis arvensis* L.: Flowering and stem elongation. *Plant Cell Env.*, **2**, 67-72 (1979).

Kadman-Zahavi, A., Gartenhause, M., The effects of light spectra fluence, duration and time of application on flowering of *Gypsophila*. *Sci. Hort.*, **40**, 237-245 (1989).

Kusey, W.E.Jr., Weiler, T.C., Hammer, P.A., Harbaugh, B.K., Wilfret, G.J., Seasonal and chemical influences on the flowering of *Gypsophila paniculata* 'Bristol Fairy' selections. *J. Amer. Soc. Hort. Sci.*, **106**, 84-88 (1981).

Lane, H.C., Cathey, H.M., Evans, L.T., The dependence of flowering in several long-day plants on the spectral composition of light extending the photoperiod. *Amer. J. Bot.*, **52**, 1000-1014 (1965).

Shillo, R., Halevy, A.H., Interaction of photoperiod and temperature in flowering-control of *Gypsophila paniculata* L. *Sci. Hort.*, **16**, 385-393 (1982).

Smith, H., Engineering phytochrome genes to improve crop performance, In: Genetic and Environmental Manipulation of Horticultural Crops (Eds. K.E. Cockshull, D. Gray, G.B. Seymour and B. Thomas) pp. 175-190. CABI Publishing, London (1998).

Suto, K., Kunishige, M., Nishio, K., Effect of temperature, photoperiod and light intensity on the growth of *Gypsophila paniculata* L. *Bull. Nat. Res. Inst. Veg. Orna. Plants Tea*, **A1**, 235-247 (1987) (In Japanese, with English summary).

Yoshimura, T., Nishiyama, M., Kanahama, K., Effects of red or far-red light and red/far-red ratio on the shoot growth and flowering of *Matthiola incana*. *J. Japan. Soc. Hort. Sci.*, **71**, 575-582 (2002) (In Japanese, with English summary).

Zande, M.T.G., Blacquière, T., Alternative source for photoperiod lighting of *Gypsophila*. *Acta Hort.*, **418**, 119-125 (1997).

Zimmer, K., Photoperiodic response of *Nigella damascene*. *Gartenbauwissenschaft*, **53**, 260-262 (1988) (In German, with English summary).