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Effects of Long-Day Treatment Using Fluorescent Lamps and Supplemental Lighting Using White LEDs on the Yield of Cut Rose Flowers

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Abstract

During arching cultivation of roses in autumn and winter, long-day treatment using fluorescent lamps placed above the base of the plants slightly increased the number of cut flowers and also tended to increase the cut flower length in the first year. To further investigate these effects, the light condition of assimilation shoots was modified by supplemental lighting using white light-emitting diodes (LEDs) placed above the assimilation shoots. Supplemental lighting at two different levels of photosynthetic photon flux density (PPFD), 100 and 250 μmol m^{-2} s^{-1}, increased the number of cut flowers from the middle portion of the assimilation shoots, and the total number and weight of cut flowers according to the light intensity. Irradiation at 250 μmol m^{-2} s^{-1} PPFD also increased the number of cut flowers over 80 cm long and the length, weight and stem diameter of cut flowers over 60 cm long. Long-day treatment using fluorescent lamps did not affect the number of cut flowers in the second year. These results indicate that long-day treatment using fluorescent lamps can effectively increase the yield of cut rose flowers in some years, while supplemental lighting using white LEDs for assimilation shoots is a method of increasing it more strongly.

Discipline: Horticulture
Additional key words: assimilation shoots, cut flower quality, *Rosa hybrida*

Introduction

In Japan, roses represent the third-largest cut flower variety and are mainly harvested from autumn to next spring (Fukui 2006). When cultivating roses, two types of artificial light treatment, namely long-day treatment and supplemental lighting are assumed. The former serves the light as signals for photoperiodism and photomorphogenesis, while the latter supplies light as energy for photosynthesis (Mor et al. 1980, Nagaoka & Yamato 1996, Roberts et al. 1993, Zieslin & Mor 1990). The effects of long-day treatment with incandescent lamps (Ichimura 2001) and supplemental lighting using high-pressure sodium lamps (Oyamada et al. 1999) have been investigated in Japan, following studies in northern countries with poorer solar radiation in winter (Carpenter et al. 1972, Tsujita 1977). Although some effects of artificial light treatment on the yield of cut rose flowers are observed in these studies, the degree of their agricultural value in Japan remains debatable.

The aim of the present study is to collect fundamental data to facilitate the development of new methods using artificial light sources in rose cultivation. Experiments were designed to introduce general light sources to the arching culture system mainly adopted in rockwool culture of roses in Japan. First, bulb-type fluorescent lamps with a higher ratio of red to far-red parts of the light spectrum, lower power consumption and longer life, compared to incandescent lamps, were tested as light sources for long-day treatment. Second, the light-emitting diode (LED) units LLM series (Stanley Electric Co., Ltd., Japan) were utilized as light sources for supplemental lighting. In these products, the distribution of luminous intensity is controlled by the lenses, which enables us to supply plant parts with sufficient white light for supplemental lighting at close range. It has been reported that supplemental lighting using these products affects the growth of horticultural crops, including sweet pea (Furufuji et al. 2010), potted miniature rose (Furufuji et al. 2011) and strawberry (Hidaka et al. 2013). White LEDs are

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predominantly used, since the light color is easily tolerated by human eyes and from a commercial perspective; promising higher luminance and moderate prices.

All experiments were performed in Ibaraki prefecture, located in eastern Japan. Because the relatively abundant solar radiation in this area raised concern that the effects of long-day treatment could be easily impaired when the annual climate condition was favorable, we tried to increase the yield of cut rose flowers by supplemental lighting using white LEDs adopted for the first time for rose cultivation in our area.

Materials and methods

1. General planting methods

(1) Experiment 1

Rosa hybrida 'Rote Rose' was cultivated in a glass house in the Horticultural Institute at the Ibaraki Agricultural Center. On 31 March, 2010, five rooted cuttings were planted on the culture soil stuffed in a 20 L plastic planter. The culture soil contained light-colored Andosol, peat-moss and perlite in a proportion of 1:2:2, to which 2 g of fused magnesium phosphate, superphosphate of lime and multi-phosphate were added per 1 L of soil. Eight grams of dolomite was also added to 1 L of peat-moss in culture soil. Liquid fertilizer was prepared and supplied with the method developed by the Aichi Agricultural Research Center (Kato 1994). The arching cultivation was adopted and one shoot per plant was bent under horizontal to become an assimilation shoot on 13 July, 2010. Rose plants were grown without harvest until 7 September, 2010, when two more assimilation shoots 70 cm long were provided for each plant. Subsequently, flowers were harvested from 19 October, 2010 to 31 March, 2011 after lighting commenced as mentioned below. The glass house was heated to 18°C after 18 October, 2010, and automatically ventilated at temperatures > 25°C.

(2) Experiment 2

Rose plants were cultivated following the general planting methods mentioned above, which includes planting on 11 May, 2011, bending of the first assimilation shoot on 7 July, 2011, addition of assimilation shoots on 7 September, 2011, harvest from 13 October, 2011 to 31 March, 2012 and start of heating on 21 October, 2011.

2. Lighting and experimental sections

(1) Experiment 1

Two experimental sections were set up and designated as follows: non-treatment (NT) and long-day treatment (LD). Each experimental section included quadruplicates of planters harboring five plants. For long-day treatment, bulb-type fluorescent lamps with 1370 lm of luminous flux and 20 W of power consumption (EFG25EL/20-ZJ, Toshiba Lighting & Technology Co., Tokyo, Japan) were placed above the base of rose plants (Fig. 1A). The photosynthetic photon flux density (PPFD) was measured using Quantum sensor LI-190 SA equipped with the LI-1000 Data Logger (LI-COR, Inc., Lincoln, NE, USA) on the base to be 5 μmol m^{-2} s^{-1}. Pre-dawn and end-of-day lighting was applied to maintain daylight from 3:00 to 21:00 every day. The spectral distribution of light sources was measured using a MCPD-3000 spectrometer (Otsuka Electronics Co., Ltd., Osaka, Japan). Long-day treatment was started at 8 September, 2010. Flowering shoots from the basal portion (Fig. 1[1]) with outer petals beginning to open were harvested and the cut flower quality was investigated. Shoots from the middle portion of the assimilation shoots were bent before flowering to become part of the assimilation shoots.

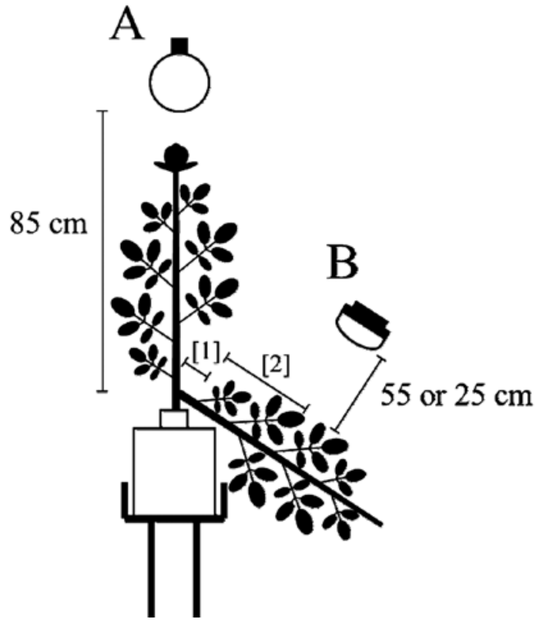

Fig. 1. Outline of lighting of rose plants

Bulb-type fluorescent lamps for long-day treatment (A) were set above the base of the rose plants. White LED units for supplemental lighting (B) were set above the assimilation shoots. The distances between the assimilation shoots and LEDs for 100 and 250 μmol m^{-2} s^{-1} PPFD were 55 and 25 cm, respectively. Flowers from the basal portion (1), within 10 cm of the base of the plant and from the middle portion of the assimilation shoots (2), the range 10–50 cm apart from the base of the plant were separately harvested.

(2) Experiment 2

Four experimental sections were set up and designated as follows: non-treatment (NT), long-day treatment (LD) and supplemental lighting at 100 or 250 μmol m^{-2} s^{-1} PPFD with long-day treatment (SL100/LD and SL250/LD). Each experimental section had a quadruplicate of planters harboring five plants. Long-day treatment was performed in the same way as Experiment 1. For supplemental lighting, light-

Table 1. Effects of non-treatment (NT) and long-day treatment (LD) on the yield and quality of cut rose flowers

Treatment	Cut flower totals[1] (plant^{-1})	Total weight of cut flowers (g plant^{-1})	Cut flower length (cm)	Cut flower weight (g)	Neck length (cm)	Number of nodes	Stem diameter[2] (mm)
NT	8.3	334.5	87.5	40.2	13.6	15.4	6.2
LD	9.4	395.5	91	42.6	13.6	15.3	6.4
t-test[3]	*	*	ns	ns	ns	ns	ns

[1] Cut flower totals from October, 2010 to March, 2011.
[2] Stem diameter measured at 1 cm above the cut end.
[3] Data are means among planters (n = 4) and ‘*’ and ‘ns’ show whether a significant difference ($P < 0.05$) was detected by the *t*-test or not.

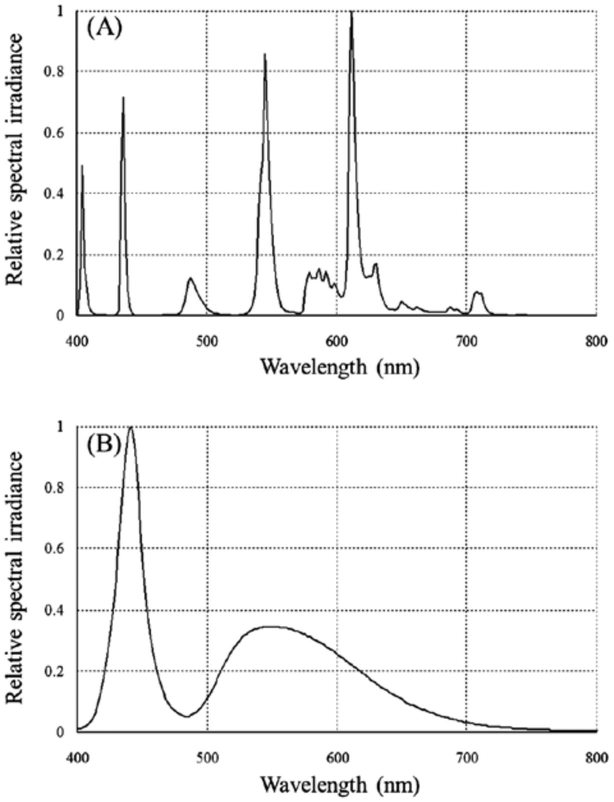

Fig. 2. Spectrum distribution characteristics of two light sources

(A) Bulb-type fluorescent lamp, (B) white LED.

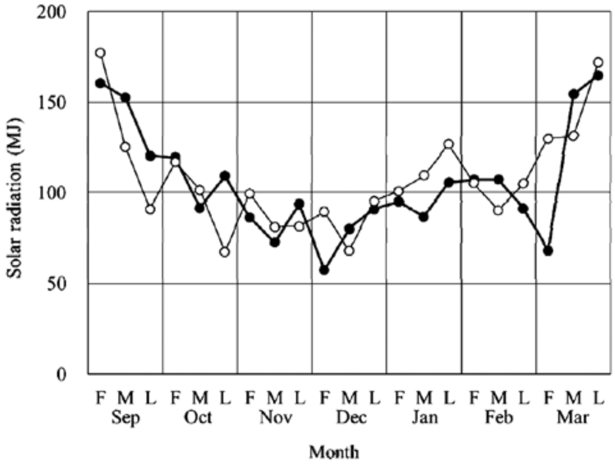

Fig. 3. Changes in the sum of daily solar radiation

The average values in the first (F), middle (M) and last (L) ten days of each month during the 2010–2011 season (open circles) and the 2011–2012 season (filled circles) are shown. These values are obtained by a meteorological observation system in the Horticultural Institute at the Ibaraki Agricultural Center.

emitting diode (LED) units with 2000 lm of luminous flux and 25 W of power consumption (LLM031, Stanley Electric Co., Ltd., Tokyo, Japan) were placed above the assimilation shoots (Fig. 1B). PPFD was measured on the assimilation shoots directly under LED. Based on knowledge of the lower light intensity limit (80 μmol m^{-2} s^{-1} PPFD) for supplemental lighting for potted roses (Furufuji et al. 2011), 100 and 250 μmol m^{-2} s^{-1} PPFD were decided as the level around the lower limit and in excess, respectively. Lighting was performed from 3:00 to 21:00 every day, based on consideration of the added effects of solar radiation and supplemental lighting in daytime and the need for the photoperiod to correspond to long-day treatment, eliminating the influence of the day length. All the above-mentioned treatments commenced on 14 September, 2011. In addition to flowering shoots from the basal portion (Fig. 1[1]), those from the middle portion of assimilation shoots (Fig. 1[2]) were harvested when the outer petals were beginning to open. This modification was due to shoot growth being promoted under the LEDs and the need to wholly understand production, preventing assimilation shoots from over-luxuriant growth. The cut flowers were divided into four classes according to length; over 80 cm (3L), 70–80 cm (2L), 60–70 cm (L) and under 60 cm (MS). The quality of cut flowers over 60 cm long was noticed to avoid the impact of inferior cut flowers.

Results

1. Effect of long-day treatment (Experiment 1)

The yield and quality of cut flowers were compared between two experimental sections, non-treatment (NT) and

Table 2. Effects of non-treatment (NT), long-day treatment (LD) and supplemental lighting at 100 and 250 µmol m^{-2} s^{-1} with long-day treatment (SL100/LD and SL250/LD) on the yield of cut rose flowers

Treatment	Cut flower totals[1] ($plant^{-1}$)			Total weight of cut flowers (g $planter^{-1}$)	Number of blind shoots[2] ($plant^{-1}$)
	Position		Total		
	Basal portion	Middle portion			
NT	7.7 a[3]	0.8 c	8.5 b	1488 c	5.8 a
LD	7.1 a	1.4 bc	8.5 b	1502 c	5.2 a
SL100/LD	8.9 a	2.3 ab	11.2 a	2082 b	4.6 a
SL250/LD	8.5 a	3.3 a	11.8 a	2426 a	3.1 a

[1] Cut flower totals from October, 2011 to March, 2012.
[2] Number of blind shoots emerged at the basal portion.
[3] Data are means among planters (n = 4) and the same letters show that a significant difference ($P < 0.05$) was not detected by Tukey's test.

Table 3. Effects of non-treatment (NT), long-day treatment (LD) and supplemental lighting at 100 and 250 µmol m^{-2} s^{-1} with long-day treatment (SL100/LD and SL250/LD) on the quality of cut rose flowers over 60 cm long

Treatment	Cut flower length (cm)	Cut flower weight (g)	Neck length (cm)	Number of nodes	Stem diameter[1] (mm)
NT	75.2 b[2]	36.8 c	11.5 ab	15.3 a	5.9 b
LD	77.6 ab	37.9 bc	12.1 a	15.1 a	6.0 b
SL100/LD	76.6 b	41.1 b	11.2 b	15.1 a	6.2 ab
SL250/LD	80.0 a	45.5 a	11.2 b	15.1 a	6.3 a

[1] Stem diameter measured at 1 cm above the cut end.
[2] Data are means among planters (n = 4) and the same letters show that a significant difference ($P < 0.05$) was not detected by Tukey's test.

long-day treatment (LD). In the bulb-type fluorescent lamps used for long-day treatment, typical three main peaks with blue, green and red light emitted from fluorescent substances were observed (Fig. 2A). Daily solar radiation was lowered toward December and long-day treatment was performed to cover it (Fig. 3). As shown in Table 1, LD resulted in 13 and 18% increases in the number and total weight of cut flowers respectively. The length, weight and stem diameter in LD tended to exceed those in NT, but the difference was minor.

2. Effect of long-day treatment and supplemental lighting for assimilation shoots (Experiment 2)

The yield and quality of the cut flowers were compared between four experimental sections, NT, LD and supplemental lighting at 100 and 250 µmol m^{-2} s^{-1} photosynthetic photon flux density (PPFD) with long-day treatment (SL100/LD and SL250/LD). In the light-emitting diodes (LEDs) used for supplemental lighting, peaks originating from a blue LED and yttrium-aluminum-garnet (YAG) fluorescent substances were observed (Fig. 2B). From October 2011 to March 2012, one flowering cycle took about two months and three peaks of harvest occurred in all four experimental sections (Fig. 4). On the one hand, LD showed no significant effect on the total number of cut flowers, affecting neither the total cut flower weight nor the number of blind shoots, most of which were of the rosette type (Fig. 4, Table 2). In LD, the number of cut flowers over 80 cm long increased (Fig. 5) with a minor increase in the length and weight of cut flowers, neck length and stem diameter (Table 3). Conversely, the number of cut flowers increased every two months for the SL100/LD and SL250/LD. As shown in Table 2, these treatments resulted in 32 and 39% increases in the total number of cut flowers, compared to that in NT, respectively. An increase in the number of cut flowers from the middle portion of assimilation shoots was significant in the SL100/LD and SL250/LD, which contributed to the increase in the total number of cut flowers, particularly in the SL250/LD. The total weight of cut flowers also increased in the SL100/LD and SL250/LD, while the number of blind shoots tended to decrease in the SL250/LD. The number of cut flowers over 80 cm long increased in the SL250/LD; most of which from the basal portion (Fig. 5). The length and weight of the cut flowers increased in the SL100/LD and SL250/LD, compared to those in NT, although the increase in length was minor in the SL100/LD (Table 3). The neck length in the SL100/LD and SL250/LD was comparable to that in NT, but lower than that in LD. While the number of nodes remained unchanged among all experimental sections, the stem diameter increased in the SL250/LD.

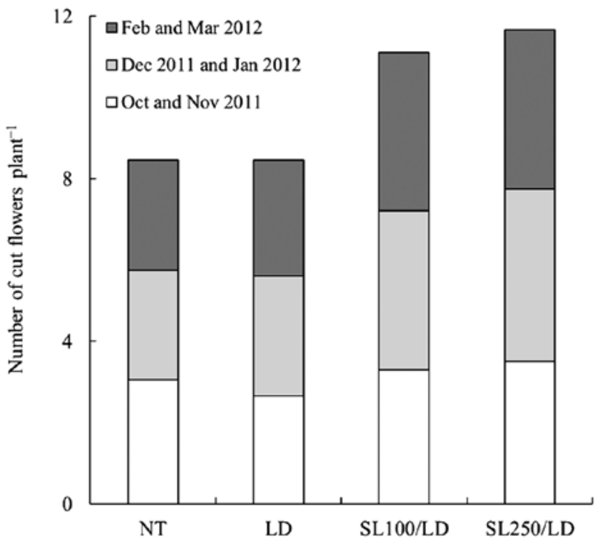

Fig. 4. Effects of non-treatment (NT), long-day treatment (LD) and supplemental lighting at 100 and 250 µmol m^{-2} s^{-1} with long-day treatment (SL100/LD and SL250/LD) on the number of cut rose flowers

The cut flower totals every two months were shown according to the harvest cycle. Data are means among planters (n = 4).

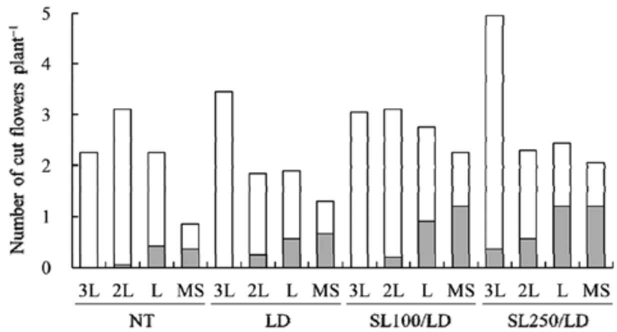

Fig. 5. Effects of non-treatment (NT), long-day treatment (LD) and supplemental lighting at 100 and 250 µmol m^{-2} s^{-1} with long-day treatment (SL100/LD and SL250/LD) on the classification of cut rose flowers

The totals of flowers over 80 cm long (3L), 70–80 cm (2L), 60–70 cm (L) and 40–60 cm (MS) harvested from the basal portion (white bars) and the middle portion (gray bars) of assimilation shoots are shown. Data are means among planters (n = 4).

Discussion

The first aim of the present study was to clarify the effect of long-day treatment using bulb-type fluorescent lamps on the yield of cut rose flowers. To confirm the results obtained in the first experiment in the 2010–2011 season, the effects of long-day treatment were re-examined in the 2011–2012 season. Supplemental lighting for assimilation shoots was also adopted assuming that long-day treatment would be less effective under fine climate conditions because our institute is located in an area with relatively abundant solar radiation in winter. Although long-day treatment increased the number of cut flowers by 13% in the first year, that performed in the second year showed no clear impact on the number, despite the increased ratio of cut flowers over 80 cm long. In the second year, enhancement of assimilation shoots was restricted by modulation of the harvest method and the total solar radiation from September to November exceeded that in the first year by 7%, which might have impaired the effect of long-day treatment on bud sprouting. Based on these observations, it is suggested that long-day treatment using fluorescent lamps increases the yield of cut rose flowers in some years, but the effect seems relatively slight.

Elucidation of the effects of supplemental lighting using light-emitting diodes (LEDs) for assimilation shoots is the second aim of the present study. Supplemental lighting at photosynthetic photon flux density (PPFD) of 100 and 250 µmol m^{-2} s^{-1} with long-day treatment not only increased the total number of cut flowers from the middle portion of assimilation shoots, but also the number of cut flowers over 70 cm long from the basal portion. The rate of increase in the number of cut flowers by LED supplemental lighting far exceeded that by long-day treatment in the first year, which may be due to the promotion of photosynthesis in assimilation shoots by supplemental lighting; considering the fact that LED lighting in a similar cultivation system increases the photosynthetic rate (Kumazaki et al. 2012), whereas photosynthates are translocated from assimilation shoots to sink organs like flowering shoots and roots in rose (Kajihara et al. 2000). However, the effect of irradiation could not be considered sufficient because the difference between 100 and 250 µmol m^{-2} s^{-1} PPFD was not significantly reflected in the total number of cut flowers. Three perspectives are needed to investigate the effects of supplemental lighting in more detail in future study. First, the cut flower quality may be improved more significantly when shoots from the middle portion of the assimilation shoots are bent to play an assimilatory role before flowering, and only the basal shoots are allowed to grow for cut flowers. Second, as substantial promotion of the photosynthetic rate might have reached its limit at 250 µmol m^{-2} s^{-1} PPFD due to the low CO_2 concentration. CO_2 enrichment is often combined with supplemental lighting (Oyamada et al. 1999), which could further improve the yield and quality of cut rose flowers. Third, there are some reports that suggest the advantages of red light in roses to facilitate translocation (Mor et al. 1980, Roberts et al. 1993) or photosynthesis (Paradiso et al. 2011), while the contribution of red light, as judged by the spectral characteristics, is relatively low in the white LEDs used here. Red light should be added when the light quality has to be considered to effectively promote photosynthesis. Nevertheless, in the present study, LED supplemental lighting was successfully established as a means of increasing the yield of cut rose flowers more than long-day treatment, showing the potential of white LEDs for use in the greenhouse cultivation of ornamental flowers.

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