Effects of Temperature and Timing/Duration of Night Cooling Treatments on Flowering Time and Quality of Cut Flowers of Standard Type Carnation (*Dianthus caryophyllus*)

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The aim of this study was to develop efficient night cooling technology to produce high-quality carnation cut flowers. The effects of temperature and timing of night cooling treatments (applied using a heat pump) on the flowering time and quality of cut flowers were investigated for standard type carnation flowers grown in a greenhouse in hot conditions. In the first experiment, rooted cuttings of the carnation ‘Exceria’ were planted in a greenhouse on July 6, 2012. Night cooling treatments at 18°C, 21°C, and 24°C were carried out, and the harvested cut flowers were compared with those of a non-cooled control group. For flowers harvested in November, those from plants subjected to the night-cooling treatments had harder stems compared with those of the non-cooled control. In the next experiment, to determine the best timing and duration of the night cooling treatment, we applied three treatments to rooted cuttings planted on June 18, 2013; overnight cooling from sunset to sunrise, cooling for 4 h from sunset (End of Day cooling: EOD-cooling), and cooling for 4 h before sunrise (End of Night cooling: EON-cooling), and compared them with a non-cooled control. For flowers harvested in December, the node order of flowering was the same in the EOD-cooling treatment and the overnight cooling treatment, and was lower than those in the EON-cooling treatment and the non-cooled control. The number of days to flowering was shorter in the EOD-cooling treatment than in the non-cooled control. In October and November in the harvest season when the high temperature influenced the early growth stage, the stem quality of cut flowers was improved by night-cooling treatments, as indicated by a significantly smaller stem weeping angle than that in the non-cooled control group. These results suggested that an EOD-cooling treatment at 21°C for 4 h from sunset was as effective as an overnight cooling treatment to improve the quality of cut flowers by promoting stem hardness and flowering. This method is a cost-effective and efficient thermal management strategy to produce high-quality carnation cut flowers in hot conditions.

Key Words: days to flowering, heat pump, node order of flowering, stem hardness.

Introduction

Carnation (*Dianthus Caryophyllus* L.) is one of the most important cut flowers worldwide. In Japan, about 240,000,000 cut flowers per year are grown in greenhouses (Statistics Department of the Minister’s Secretariat at the Ministry of Agriculture, Forestry and Fisheries, Japan, 2017). The cropping timing for a mild climate, for example, in Aichi and Hyogo prefectures, is to plant from June to July and harvest from October to May. Approximately 63% of carnations in Japan are grown under these conditions, and the other 37% are...
grown in a cold climate, for example, in Hokkaido and Nagano prefectures (Ministry of Agriculture, Forestry and Fisheries, Japan, 2016).

Simulation models have predicted that changes in global mean surface temperatures will be between 0.3°C and 4.8°C by the end of the 21st century (IPCC, 2013). The average air temperature in summer has been increasing by about 1.1°C per 100 years as a result of meteorological changes (Japan Meteorological Agency, 2019). Average day temperatures ranging from 18/11°C (day/night) produce the highest quality carnation flowers (Hanan, 1959). Higher temperatures can result in delayed flowering and low quality cut flowers, including softer stems. These become issues in mild-climate cropping during fall to early winter (Yamaguchi, 1991), when the primary cut flower is derived from the first lateral shoot. A delay in primary flowering leads to delayed flowering from the second lateral shoot and a total yield reduction in mid-May, when there is a high demand for flowers for Mother’s Day.

Night cooling treatments can reduce the incidence and severity of various physiological disorders caused by high temperatures in horticultural crops grown in greenhouses (Sato et al., 2013b). Recently, increasing crude oil prices have accelerated the introduction of heat pump equipment to control the temperature inside greenhouses in winter. Since heat pumps have dual functions of heating and cooling, they can also be used to apply night cooling treatments in summer (Hayashi et al., 1983). Consequently, there have been many studies on both qualitative and quantitative improvements in greenhouse-grown ornamental flowers in Japan by applying night cooling treatments using a heat pump. Night cooling treatments have been shown to prevent rosette formation in seedlings in Eustoma russellianum (Hirai and Mori, 1999), and to increase the weight and length of rose cut flowers (Kajihara et al., 2015; Sato et al., 2013a) and Oriental lily (Ninomiya et al., 2012). Kajihara et al. (2015) developed a low-cost method with a shorter cooling treatment time (4 h from sunset instead of overnight) to maintain the quality of cut rose flowers.

Previous studies have shown that the development and elongation of lateral shoots were promoted by night cooling at 13°C, 16°C, and 19°C in the standard type carnations ‘Scania’ and ‘La Reve’ (Hattori et al., 1982). In the spray type carnation ‘Light Pink Barbara’, both the weight and length of cut flowers were increased by spot cooling at 21°C at night (Kajihara et al., 1997). These results indicate that night cooling can positively affect carnation flowers.

The aim of this study was to develop efficient night cooling technology using a heat pump for carnations growing in a greenhouse under hot conditions. The effects of the temperature and timing of the cooling treatment on the flowering time and quality of cut flowers of standard type carnation were investigated.

**Materials and Methods**

**Cultivation conditions**

The standard type carnation ‘Exceria’ was used in this study. Rooted cuttings were produced by the usual method and planted with spacing of 20 cm × 10 cm in a polypropylene bed [Drain-bed 85 (0.85 m wide × 2.0 m long × 0.17 m deep); National Federation of Agricultural Cooperative Associations, Tokyo, Japan] filled with mixed soil [65% peat moss, 15% decomposed granite soil, 10% perlite, 10% Akadama (red granular soil)]. A trellis net with eight lanes was used to prevent lodging; rooted cuttings occupied six lanes, and the other two were the center lanes. The bed was coated with light reflective film (Poly-Shine NF; Hitachi AIC, Tochigi, Japan). Nutrient solution was supplied through a watering tube. The top bud was pinched to leave five nodes, then each plantlet was trimmed to leave four lateral shoots. The experiments were carried out in a glass greenhouse (3 m wide × 4 m deep × 3 m height) at the Awaji Agricultural Technology Center. The conditions of night cooling were examined in terms of temperature (Experiment 1) and timing/duration (Experiment 2). These experiments were conducted with the working schedules described below.

Experiment 1; planted on July 6, 2012; pinching on July 30; night cooling from August 13 to September 25; trimming on August 22; heating to 10°C minimum temperature from November 29 to December 31; heating to 13°C minimum temperature from January 1 to April 30; harvesting in November and December.

Experiment 2; planted on June 18, 2013; pinching on July 9; night cooling from July 9 to September 25; trimming on August 14; heating to 10°C minimum temperature from December 1 to 31; heating to 13°C minimum temperature from January 1 to April 30; harvesting in October, November, and December.

**Night cooling treatments**

For the night cooling treatments in Experiment 1, the temperature was set at three levels; 18°C, 21°C, and 24°C, with a non-cooled control treatment (ambient greenhouse temperature). For the night cooling treatments in Experiment 2, the timing of the cooling treatment (21°C) was from sunset to sunrise, for 4 h from sunset (End of Day cooling: EOD-cooling), and for 4 h before sunrise (End of Night cooling: EON-cooling), with a non-cooled control. The start and end times of the cooling treatments were adjusted weekly according to the times of dawn and sunset in Kobe city in Japan. The night cooling treatments were applied using a household air conditioner [S50NTEP (5 kW); DAIKIN INDUSTRIES, Osaka, Japan]. Temperature data were recorded every 30 min by temperature sensors with a ventilating function (R220 series temperature/humidity transducers; CHINO Corporation, Tokyo, Japan) in Experiment 1, and every 10 min by a compact data logger
(Thermo Recorder TR-71S; T&D Corporation, Nagano, Japan) in Experiment 2. Both roof and side windows were closed during the night-cooling treatment in the greenhouse.

**Characterization of cut flowers**

Flowers were harvested when the outer petals emerged horizontally. Days to flowering were counted from the day the top bud was pinched to the day primary cut flower was harvested. Node order at flowering was determined within the primary lateral branch. As the first flower, the primary lateral branch was harvested at eight nodes from the top. As the second flower, the secondary lateral branch was harvested at 10 nodes from the top. Cut flower length, fresh weight, diameter of the central part of the fifth internode from the bud, flower diameter, and stem weeping index (SWI) were measured. The SWI was determined as follows: < 10°, 1; 10° to 20°, 2; 20° to 30°, 3; > 30°, 4. In Experiment 2, the stem weeping angle (SWA) was used instead of SWI to evaluate the weeping level more accurately. SWA was measured as the angle between a horizontal line and a line connecting the center of the bud to the held position, 45 cm away from the flower top. The number of cut flowers was counted every month from the beginning of flowering to May 15 (Experiment 1) or May 20 (Experiment 2). The number of cut flowers was represented as the per unit area (m²) under cultivation.

Data shown in Figures and Tables are the mean ± standard error of three replication bulks. A replication bulk consisted of 11 to 12 stocks, based on a missing plant during cultivation as described by Yamanaka et al. (2011). Statistical analyses were performed using Microsoft Excel. The significance of differences among groups was determined using Tukey’s test.

**Table 1.** Effects of night cooling treatment temperature on cut flower quality of carnation.

| Treatment  | Cut flower length (cm) | Fresh weight (g) | Stem diameterz (mm) | SWI y (1–4) | Flower Diameterx (mm) |
|------------|------------------------|------------------|---------------------|-------------|----------------------|
| **November** |                        |                  |                     |             |                      |
| 18°C       | 64.0a*                 | 26.3a            | 3.9a                | 1.8b        | 69.7a                |
| 21°C       | 61.9a                  | 25.6ab           | 4.0a                | 1.6b        | 71.0a                |
| 24°C       | 64.8a                  | 25.2ab           | 4.3a                | 1.8b        | 68.2a                |
| non-cooling | 61.5a                  | 22.9b            | 4.0a                | 2.8a        | 69.0a                |
| **December** |                      |                  |                     |             |                      |
| 18°C       | 67.5a                  | 30.2a            | 4.5a                | 1.9a        | 74.3a                |
| 21°C       | 67.6a                  | 30.6a            | 4.6a                | 1.8a        | 73.0a                |
| 24°C       | 66.8a                  | 29.6a            | 4.5a                | 2.3a        | 75.4a                |
| non-cooling | 65.8a                  | 29.2a            | 4.6a                | 2.4a        | 73.5a                |

* Maximum diameter of center of upper fifth internode.

7 SWI (stem weeping index) was determined from stem the weeping angle (angle between the horizontal line and line connecting center of the bud to the held position 45 cm away from the flower top); <10°, 1; 10° to 20°, 2; 20° to 30°, 3; >30°, 4.

x Maximum flower diameter when outer petals emerged horizontally.

w Different letters in each column indicate significant difference (Tukey’s test, P < 0.01).
differ significantly among cut flowers from the control and night cooling treatments at 21°C and 24°C. The SWI values, an indicator of stem hardness, were 1.8 (18°C set), 1.6 (21°C set), and 1.8 (24°C set), significantly lower than that in the control (2.8). This result indicated that night cooling was effective for hardening cut flower stems. There were no significant differences among treatments in cut flower length, stem diameter, or flower size. The quality characteristics of cut flowers harvested in December were not significantly different among treatments. There was no significant difference in each total yield (number of cut flowers per square meter) except for flowers harvested in November and March (Fig. 2). The total yield in November was 29.4 in the 21°C night cooling treatment, significantly higher than that in the 24°C treatment, enabling us to determine the optimal temperature condition in Experiment 2. In March, the monthly yield was lower from night-cooling treatments than from the control.

**Effect of timing and duration of night cooling treatments on flowering time and cut flower quality (Experiment 2)**

Experiment 1 revealed that night cooling treatments could improve the quality of cut flowers, depending on the temperature and harvest season. To optimize the night cooling treatment to save energy, we evaluated the effectiveness of shorter night cooling treatments at 21°C on the timing of flowering and cut flower quality in Experiment 2. The differences in air temperature in each treatment are shown from August 22 to 23 in 2013, when the maximum air temperature was recorded in that month (Fig. 3). The average temperature during the night cooling treatment decreased from the start of the EOD-cooling treatment at 18:42. It reached the target temperature of 21°C after 88 min, and dropped to 20.3°C at the end of the treatment. The average temperature during the EOD-cooling treatment was 22.0°C. In the EON-cooling treatment, the temperature decreased from the start of the treatment at 1:23, reached the desired temperature of 21°C after 47 min, and then dropped to 19.2°C, with an average temperature of 20.8°C. In the overnight cooling treatment (overnight), the temperature was kept around 21°C from 98 min after treatment until the treatment ended at 5:23 with an average temperature of 21.5°C. The average temperatures during the night were 25.1°C (EOD-cooling), 26.0°C (EON-cooling), and 28.9°C (non-cooling), respectively.

For flowers harvested at the end of December, the number of days to flowering was 111 in the EOD-cooling treatment, significantly fewer than in the control (126) (Fig. 4), but not significantly different from that in the EON-cooling and overnight cooling treatments. The node orders at flowering were 18.6 (EOD-cooling) and 18.8 (overnight), both significantly lower than those of 20.2 (EON-cooling) and 20.6 (non-cooling). The node orders did not differ significantly

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**Fig. 2.** Effects of different night cooling temperatures on cut flower yields of carnation. For experimental details, see Figure 1. Different letters in each column indicate significant difference among treatments in each month (Tukey’s test, P < 0.05). Vertical bars indicate SE (n = 3).

**Fig. 3.** Mean air temperature the in greenhouse from August 22 to 23 in 2013. In Experiment 2, the three treatments were overnight cooling at 21°C from sunset to sunrise (overnight), cooling for 4 h from sunset (End of Day cooling: EOD-cooling), and cooling for 4 h before sunrise (End of Night cooling: EON-cooling). Non-cooling; no cooling treatment. For other experimental details, see Figure 1.
between the EOD-cooling and overnight cooling treatments, or between the EON-cooling treatment and the control (Fig. 4). The ratio of cooling degree-hours in EOD-cooling against overnight cooling was 54%, while that in EON-cooling was 39% (data not shown).

For cut flowers harvested in October, the cut flower length was 61.4 cm in the overnight cooling treatment, but only 54.1 cm with EON-cooling (Table 2). The flower fresh weight was significantly higher in the overnight cooling treatment (17.9 g) than in the control. The stem diameter was longer in the overnight cooling treatment (3.5 mm) than in the control (3.1 mm). The SWA was significantly smaller in the night cooling treatments (16.8° in EOD-cooling, 14.7° in EON-cooling, and 15.0° in the overnight cooling treatment) than in the control (23.0°). These data confirmed that night cooling treatments hardened the stems of cut carnation flowers.

For cut flowers harvested in November, the fresh weight in the overnight cooling treatments was 21.7 g, significantly heavier than that in the control (19.5 g) (Table 2). The SWA was significantly smaller in the night cooling treatments (13.2° in EOD-cooling and EON-cooling, and 13.3° in the overnight cooling treatment) than in the control (20.1°). Therefore, the night cooling treatments had the same effect on stem hardness for flowers harvested in October and November. There was no significant difference in flower quality among the treatments. The flower diameter did not change significantly during the three months from October to December.

The monthly total yields of cut flowers are summarized in Figure 5. There was no significant difference in total yields among the treatments, except in February, when the yield was higher in EON-cooling and overnight cooling treatments (15.7) than in the control (6.9).

### Table 2. Effects of timing/duration of night cooling treatments on cut flower quality of carnation.

| Treatment  | Cut flower length (cm) | Fresh weight (g) | Stem diameter (mm) | SWA (°) | Flower Diameter (mm) |
|------------|------------------------|------------------|--------------------|---------|----------------------|
| **October** |                        |                  |                    |         |                      |
| EOD-cooling | 58.6ab^t              | 15.9ab           | 3.2ab              | 16.8b   | 56.9a                |
| EON-cooling | 54.1b                 | 15.4ab           | 3.2ab              | 14.7b   | 57.8a                |
| overnight  | 61.4a                  | 17.9a            | 3.5b               | 15.0b   | 58.8a                |
| non-cooling | 56.0ab                | 14.5b            | 3.1a               | 23.0a   | 58.3a                |
| **November** |                       |                  |                    |         |                      |
| EOD-cooling | 59.8a                 | 21.0ab           | 3.8a               | 13.3b   | 63.6a                |
| EON-cooling | 58.6a                 | 19.7ab           | 3.7a               | 13.3b   | 63.0a                |
| overnight  | 61.4a                  | 21.7a            | 3.8a               | 13.2b   | 63.8a                |
| non-cooling | 59.2a                 | 19.5b            | 3.7a               | 20.1a   | 64.1a                |
| **December** |                       |                  |                    |         |                      |
| EOD-cooling | 63.3a                 | 26.2a            | 4.1a               | 12.3a   | 69.9a                |
| EON-cooling | 61.1a                 | 24.3a            | 3.8a               | 14.0a   | 70.8a                |
| overnight  | 57.2a                  | 23.1a            | 3.8a               | 13.8a   | 66.1a                |
| non-cooling | 63.3a                 | 26.5a            | 4.0a               | 13.9a   | 74.9a                |

^t Three treatments were 21°C from sunset to sunrise (overnight), cooling for 4 h from sunset (End of Day cooling: EOD-cooling), cooling for 4 h before sunrise (End of Night cooling: EON-cooling). Non-cooling; no night cooling treatment.

^x Maximum diameter of center of upper fifth internode.

^y SWA (stem weeping angle): angle between a horizontal line and a line connecting the center of the bud to the held position 45 cm away from the flower top.

^w Maximum flower diameter with outer petals positioned horizontally.

^z Different letters in each column indicate significant difference (Tukey’s test, P<0.01).
Discussion

In this study, we analyzed the effect of entire or partial night cooling treatments on both the quality and quantity of carnation cut flowers. We showed that cooling treatment improved the quality of cut flowers by promoting stem hardness and flowering, but had a small effect on quantity in terms of both weight and yield. Moreover, we found that EOD-cooling, a partial night cooling treatment, was a practical technique to produce high quality carnations.

Carnations with soft and weak stems have little commercial value. Numao (2012) reported that the permissible range of SWA was less than 30° (less than 3 in SW1) for shipping cut carnation flowers. In Experiment 1, for cut flowers harvested in November, those from the night-cooling treatment groups cooled at 18°C, 21°C, and 24°C had harder stems (lower SWI) than those in the control group (Table 1). In a previous study, a night cooling treatment at 21°C applied to the spray type carnation ‘Light Pink Barbara’ planted in May significantly reduced the SWI (Kajihara et al., 1997). This treatment was applied using a spot cooler to plants in a cultivation bed covered by vinyl film at night. Therefore, the stem hardness of both standard type and spray type carnations can be improved by night cooling treatment.

In this study, we detected significant differences in SW1 and stem weeping angle (SWA) between the control and night cooling treatments for flowers harvested in November in Experiment 1, and for flowers harvested in October and November, but not December, in Experiment 2 (Table 2). Translocation of photosynthetic assimilates may have been promoted by the temperature drop with night cooling treatments in both the October and November harvests. Factors that regulate stem hardness include temperature, light, nutrient availability, and humidity (Yamaguchi, 1991). Among these factors, temperature strongly affects stem hardness, because flower stems harvested in hot seasons are known to be much softer than those harvested in cooler seasons (Hosoya and Hayashi, 1977). Harris and Jeffcoat (1974) showed that the stem hardness depended on temperature-dependent changes in the distribution of photosynthetic assimilates into each organ: 40% of photosynthetic was distributed into the flower bud and stem at 22°C, compared with 30% and 50% at 12°C. They reported that the activity of invertase in flower petals was reduced by low temperature, which restricted the movement of assimilates into the flower and resulted in accumulation inside the stem.

Yamaguchi (1991) reported that ethychlozate, which has auxin-like properties, reduced the SWA in carnation due to lignification of the vascular bundle. A similar effect on stem quality by auxin has also been reported in Arabidopsis. Comparing cross-sections of stems grown at −10 DIF [12/22°C (day/night)] and +10 DIF [22/12°C (day/night)], the stem and pith areas were larger and the pith contained more cells in the +10 DIF treatment (Thingnaes et al., 2003). Moreover, plantlets in the +10 DIF treatment contained higher levels of indole acetic acid. In Experiment 2, the stem diameter of flowers harvested in October was longer in the overnight cooling treatment than in the control, which is consistent with the lower SWA (Table 2). The decrease in SW1 and SWA could be due to hypertrophy and hardening of stems caused by auxin secretion under night-cooling conditions. We previously observed that the stems tended to become harder with decreasing node order (Higashiura et al., 2018). This may have been caused by the larger difference in DIF, since the lower young nodes had formed during a hot season with night cooling.

In Experiment 1, the weight of cut flowers harvested in November was higher in the 18°C night cooling treatment than in the control. An increase in cut flower weight by night cooling treatments has been observed in rose (Kajihara et al., 2015) and lily (Ninomiya et al., 2012). In lily, the respiration rate decreased and the dry/fresh weight ratio of the leaves increased as the DIF tended towards negative values with reduced night temperatures (Inamoto et al., 2016). This may be the main reason for the increase in flower weight in the night cooling treatments in Experiment 1. The difference in

Fig. 5. Effects of different timing/durations of night cooling treatment on cut flower yields of carnation. For experimental details, see Figure 3. Different letters in each column indicate significant difference among treatments in each month (Tukey’s test, \( P < 0.05 \)). Vertical bars indicate SE (\( n = 3 \)).
flower weight between the control and overnight cooling treatments was higher in October and November than in December (Tables 1 and 2), indicating that the effect of night cooling is greater when the seasonal temperatures are higher. In Experiment 2, the cut flower weight was not affected by EOD-cooling or EON-cooling, but was increased by the overnight cooling treatment. In rose, a 4-h EOD-cooling treatment significantly increased the cut flower weight, possibly by promoting translocation and inhibiting respiratory consumption (Kajihara et al., 2015). A 4-h EOD-cooling treatment may be too short to observe such an effect in carnation. Another reason may be a difference in the cumulative temperatures between the two studies, caused by a time lag to reach the preset temperature. It took less than 10 minutes in the case of rose (Kajihara et al., 2015), but almost 90 minutes in our experiment.

The integrated yield of cut flowers all through the harvesting period was not affected by any of the treatments in Experiments 1 and 2 (Data not shown). However, in a previous study on the standard type carnation ‘Scania’, the total yield of cut flowers was increased by night cooling from July to August (Hattori et al., 1982). This inconsistency may be due to differences in weather conditions between studies or differences among carnation varieties.

In carnation, flowering is promoted when the day temperature is relatively high and the night temperature is low. For ‘William Sim’ carnations grown under a 16-h light/8-h dark photoperiod, the number of days to flower differentiation was 88 and the node position of flowering was 25.8 at 24/24°C (day/night), compared with 74 and 21.0, respectively, at 24/12°C (Dahab, 1967). This promotion of flowering was due to the positive DIF. In the present study, the positive DIF of the EOD-cooling treatment may be one factor that promoted the flowering of the first flowers from September to December in Experiment 2. The promotion of flowering by DIF differs among plant species depending on their sensitivity and preference, such as positive, zero, or negative DIF (Myster and Moe, 1995).

In Experiment 2 in our study, the positive DIF of the night cooling treatments resulted in earlier flowering with decreasing node order (Fig. 4). Some molecular studies reported flowering control with DIF by gene expression in *Arabidopsis*. A +10 DIF [22/12°C (day/night)] delayed flowering compared with 0 DIF [22/22°C (day/night)], possibly because of the temperature-dependent expression of the flowering-relate genes Constans (*CO*) and Flowering locus T (*FT*) (Kinmonth-Schultz et al., 2016). Normally, *FT* expression increases at sunset and decreases at sunrise. When flowering was inhibited by night cooling, *FT* expression was restrained at sunset and enhanced at sunrise. It is unclear whether negative or positive DIF promotes flowering in *Arabidopsis* and carnation, and expression profiling of these genes will generate basic information about flowering in carnation.

The EOD-cooling treatment, but not the EON-cooling treatment, had the same effect on flowering as the overnight cooling treatment. The average temperature in the 4 h from sunset was 8.3°C lower in EOD-cooling than in the control, suggesting that a more positive DIF may promote flowering. Even though the average temperature in the 4 h before sunrise was 6.8°C lower in the EON-cooling treatment than in the control, flowering was not promoted in the EON-cooling treatment. These results suggest that the high expression level of the *FT* gene at sunset may be related to flowering in carnation. The whole genome of carnation has been sequenced (Yagi et al., 2014) and post-genomic studies have revealed orthologs for *Arabidopsis* genes related to flowering, such as MADS-BOX genes (Zhang et al., 2018). It will be important to clarify the relationship between these genes and the promotion of flowering by DIF and EOD-cooling in carnation.

In conclusion, overnight cooling improved the quality of cut flowers in autumn by hardening stems and promoting flowering. An EOD-cooling treatment (21°C for 4 h from sunset) was as effective as overnight cooling, and therefore represents a cost-effective and efficient thermal management strategy for the production of high-quality carnation cut flowers in hot conditions.

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