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Developmental Stage and Temperature Influence Elongation Response of Petiole to Low Irradiance in *Cyclamen persicum*

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Abstract. Reduced irradiance promotes shoot elongation depending on developmental stage and environmental factors and decreases plant quality in *Cyclamen persicum* Mill. To determine the petiole elongation responses to low irradiance, 'Metis Scarlet Red' cyclamen at different developmental stages [juvenile (5-6 unfolded leaves), transitional (1-3 visible flower buds), or mature (1-3 elongating peduncles)] was grown in growth modules at 60 (low light, LL) or 240 (high light, HL) $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD within the growth chambers at different temperatures [16/12 (low temperature, LT), 22/18 (medium temperature, MT), or 28/24℃ (high temperature, HT) (day/night)]. In Experiment I, juvenile plants were either kept in an LL or HL module during the entire treatment of 4 weeks or were transferred to the other module at 1, 2, or 3 weeks after treatment in an MT chamber. In Experiment II, juvenile, transitional, or mature plants were moved to the HL module at 0, 3, 6, 9, or 12 days after being placed in the LL module at the MT chamber and grown for 21 days. In Experiment III, transitional plants were moved to the HL module at 0, 3, 6, 9, or 12 days after being placed in the LL module at the LT, MT, or HT chambers. As the exposure duration to LL increased from 0 to 4 weeks or from 0 to 12 days, petiole length and plant height increased at all temperatures and developmental stages. In Experiment I, the exposure to LL during the latter period, rather than the early period, increased elongation rate. In Experiment II, petiole elongation in transitional plants was more sensitive to LL than juvenile or mature plants during the early period of the treatment for 12 days. In Experiment III, petiole length increased with increasing temperature and exposure duration to LL. Petiole elongation rate at HT increased rapidly from the beginning of LL exposure as compared to LT. Increase of 6℃ in temperature had the similar effect to LL exposure for 3 days in petiole elongation. To conclude, transitional cyclamen under higher temperatures responds more immediately to low irradiance and elongates its petioles.

Additional key words**:** height control, light intensity, potted plant, shade avoidance, stem extension

Introduction

Low irradiance can be considered as a stress to plants, since it can significantly reduce plant productivity (Gawronska and Dwelle, 1989). The common reactions of plants to reduced irradiance are stem elongation and leaf lamina expansion. Most plants promote shoot elongation and leaf expansion when exposed to low irradiance (Allard et al., 1991; Gawronska et al., 1995; Higuchi et al., 2001; Knecht and O'leary, 1972; Kurepin et al., 2006; Nii and Kuroiwa, 1988; Onwueme and Johnston, 2000; Potter et al., 1999; Rahim and Fordham, 1991; Tan and Qian, 2003). These plant responses to low irradiance (shade) are defined as shade avoidance responses (Smith, 1982). Shade avoiders generally tend to redirect their development in shade so that the elongation or expansion of internode, petiole, and leaf blade is favored at the expense of leaf development, thereby allowing the young leaves to be kept out of shade.

Cyclamen persicum Mill. under light deficiency develops excessively long petioles and excessively large leaves with a soft texture, and delays leaf and flower bud initiation (Dole and Wilkins, 1999; Le Nard and de Hertogh, 1993; Widmer, 1992). Morel Diffusion, a major cyclamen breeding and distributing company, recommends supplemental lighting applied from November until February/March (http://www.cyclamen.com).

Morphological changes by reduced irradiance can be shown

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at different times and degrees depending on light level, temperature, developmental stage, genotype, and so on. Seedlings of *Brassica napus* (Potter et al., 1999), *Stellaria longipes* (Kurepin et al., 2006), and *Allium sativa* (Rahim and Fordham, 1991) showed increase in plant height at day 7, in shoot elongation rate at day 4, and in leaf length at day 10 after low irradiance treatment, respectively. Although reports on the interaction between temperature and irradiance in elongation growth are somewhat equivocal, high temperatures and low irradiances increased stem length in some plants (Davies et al., 2002; Menzel, 1985; Pinthus and Abraham, 1996).

Leaf growth of cyclamen under low irradiance seems to be influenced by temperature because it has longer petioles and larger blades in summer. Especially, greenhouses in rainy summer and cloudy winter seasons have the environmental condition encouraging petiole and leaf expansion. The ornamental quality of potted cyclamens, petiolate plants, is deteriorated by excessively elongated petioles and excessively large leaf lamina (Maas and van Hattum, 1998; Villegas et al., 2006).

Plant height control by suppressing sizes of petiole and lamina is essential to produce good quality potted cyclamens. However, there are only a few researches on shoot elongation responses to light intensity and temperature in cyclamen. This study was carried out to examine the changes in shoot elongation of cyclamen plants at different developmental stages grown under different temperatures with different exposure durations to low irradiance.

Materials and Methods

Plant material and culture

Plugs of 12-week-old *Cyclamen persicum* Mill. 'Metis Scarlet Red' seedling with four expanded leaves were received on 20 January from a commercial propagator (Korea-America Plug Co., Ltd., Jincheon, Korea). The seedlings were transplanted to 7 cm-diameter plastic pots filled with Sunshine Mix #1 (Sun-Gro Horticulture, Bellevue, WA, USA) and grown in a glasshouse maintained at 20 ± 4℃ and a 12-h photoperiod using natural sunlight plus compact fluorescent lamps (EFTR 20EX, Philips Electronics) until treatments.

The plants were watered using a stagnant wick subirrigation system with two nutrient solutions [150 $mg \cdot L^{-1}$ N from 20N-3.7P-16.6K (Technigro 20-9-20 Plus, Sun-Gro Horticulture, Bellevue, WA, USA) and 15N-0P-12.5K fertiliser (Technigro 15-0-15 Plus)] used on alternate days.

This experiment was carried out in three controlled environment chambers maintained at 16/12℃ (LT), 22/18℃ (MT), or 28/24℃ (HT) (day/night), respectively (Fig. 1A). Each chamber had two growth modules providing photosynthetic photon

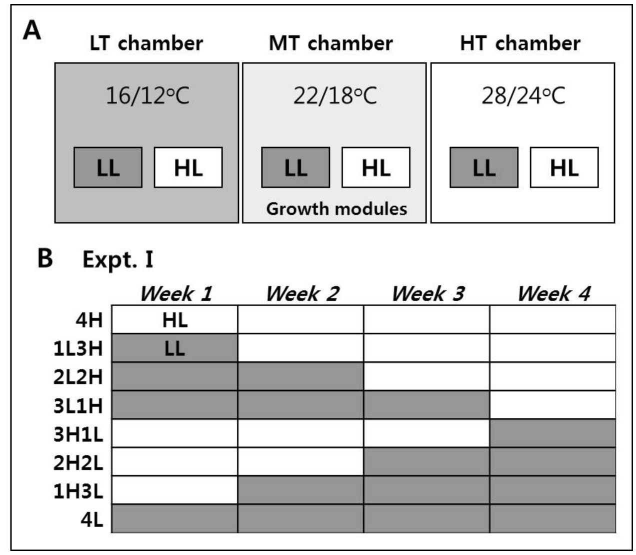

Fig. 1. Schematic diagram of growth modules in growth chambers used in this study (A) and light treatments of Experiment I (B). Three growth chambers were maintained at 16/12°C (LT), 22/18°C (MT), or 28/24°C (HT) (day/night), and each had two growth modules providing PPFD of 60 (LL) or 240 (HL) $\mu mol \cdot m^{-2} \cdot vs^{-1}$.

flux densities (PPFD) of 60 (LL) or 240 (HL) $\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively, at canopy height for a 16-h photoperiod (08:00-24:00) using fluorescent lamps (FL20EX-D, Wooree Lighting Co., Ltd., Seoul, Korea). The PPFD was measured using an LI-250A light meter with an LI-210SA photometric sensor (Li-Cor, Lincoln, NE, USA).

Light intensity and temperature treatments

Experiment I. Exposure time and duration to low irradiance

Plants with 5-6 fully-expanded leaves were moved to the LL or HL modules in the MT chamber. Fifteen plants were either kept under LL or HL during the entire treatment of 4 weeks (4L or 4H) or were moved from the LL module to the HL module at 1, 2, or 3 weeks after treatment (1L3H, 2L2H, or 3L1H) or conversely (3H1L, 2H2L, or 1H3L) (Fig. 1B). After treatment, all plants were moved to the HL module and grown for a week.

Experiment II. Exposure duration to low irradiance at different developmental stages

Seventy-five plants each at the juvenile (5-6 unfolded leaves), transitional (1-3 visible flower buds), and mature stage (1-3 elongating peduncles) were moved to the LL module in the MT chamber. Fifteen plants at each stage were transferred to the HL module after 0, 3, 6, 9, or 12 days after treatment.

Experiment III. Exposure duration to low irradiance at different temperatures

Three plant groups including 75 plants with 1-3 visible flower buds were moved to the LL module in three chambers at different temperatures (LT, MT, or HT). Fifteen plants of each group were transferred to each HL module at 0, 3, 6, 9, or 12 days after treatment. The plants at the transitional stage in Expt. II were the same to those grown at MT in Expt. III.

Data collection and analysis

Leaf morphological characteristics were collected from three recently expanded leaves for each plant at 3 weeks after treatment except for the first experiment on exposure time and duration to low irradiance where they were measured at 5 weeks after the onset of treatment. Petiole length and plant height were measured from the top of tuber to the basal end of leaf lamina and the longest point of leaf canopy, respectively.

Fifteen plants per treatment were randomly placed in each module. All experiments were carried out twice. Data was analyzed using SAS analysis of variance (ANOVA) and General Linear Models (GLM) procedures (SAS Institute Inc., Cary, NC, USA). Regression analysis was performed by Sigma Plot (SPSS, Inc., Chicago, IL, USA).

Results

Exposure time and duration to low irradiance

Petiole length and plant height increased as exposure duration to LL increased from 0 to 4 weeks irrespective of exposure time (Fig. 2). LL control (4L) plants had longer petioles by two times compared with HL control (4H) (Fig. 2A). When plants were exposed to LL prior to HL (4H, 1L3H, 2L2H, 3L1H, and 4L), LL treatment during the first week (1L3H) didn't influence petiole elongation compared with 4H. After that, as LL exposure duration increased from 2 to 4 weeks, petiole length significantly increased by 33% to 102% than 4H.

When plants were exposed to LL following HL (4H, 3H1L, 2H2L, 1H3L, and 4L), LL for only 1 week during the 4th week (3H1L) increased petiole length by 62% and 2H2L increased by 85% compared with 4H. There was no statistically significant difference among 2H2L, 1L3L, and 4L in petiole length.

Plants exposed to LL at the latter period (3H1L, 2H2L, or 1H3L) had longer petioles than those exposed at the early period (1L3H, 2L2H, or 3L1H) when they were treated to LL for the same duration (Fig. 2A). 3H1L, 2H2L, and 1H3L increased leaf petiole length by 2.30, 2.10, and 1.13 cm compared with 1L3H, 2L2H, and 3L1H, respectively. Exposure for only 1 week at the later period (3H1L) showed the effect on petiole elongation similar to LL treatment for 3 weeks at the early period (3L1H).

The same trends were found in plant height (Fig. 2B) which is thoroughly affected by the lengths of petiole and leaf lamina in cyclamen. LL control plants showed the longest plant height, 126% longer than those with 4H. Plant height increased as exposure duration to LL increased and when

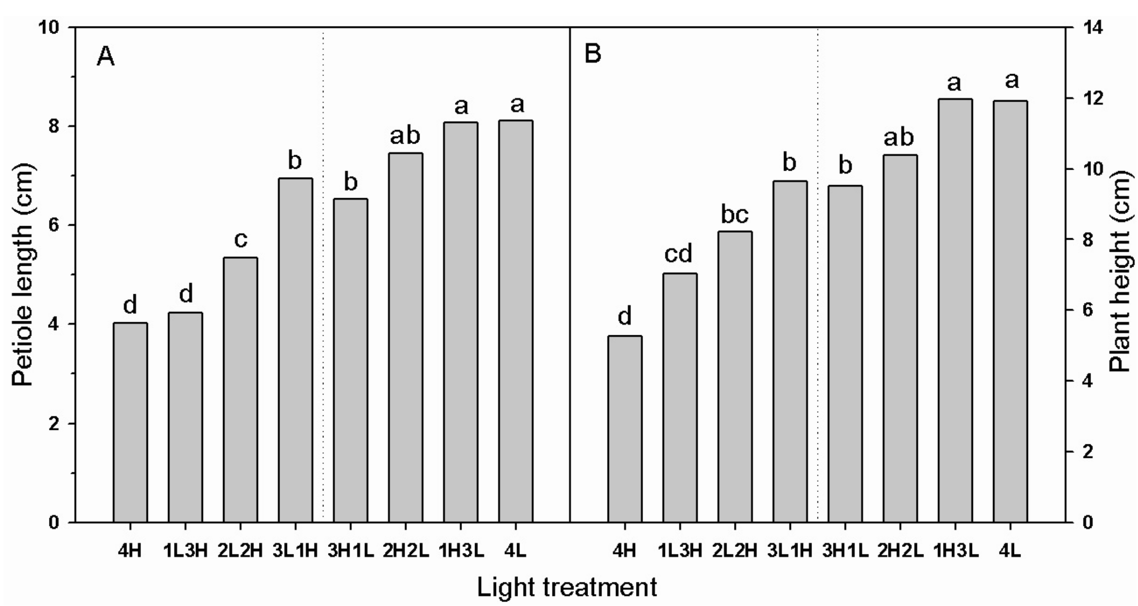

Fig. 2. Petiole length (A) and plant height (B) of *Cyclamen persicum* 'Metis Scarlet Red' grown under 22/18°C (day/night) with a 16-h photoperiod of 60±5 (LL) and/or 240±20 (HL) $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD for 4 weeks. Numerals of X axis represent the number of weeks when plants were continuously exposed to LL or HL. The order of L (LL) and H (HL) means the sequence of treatment time. Within-graph means followed by the same letter are not significantly different by Tukey's honestly significant difference (HSD) test at $P \leq 0.05$.

plants were exposed to LL at the latter period of the 4 weeks.

Exposure duration to low irradiance at different developmental stages

Petiole length and plant height increased as exposure duration to LL increased from 0 to 12 days at all developmental stages (Fig. 3). At each stage, petiole length and plant height were quadratically correlated to exposure duration to low light (Table 1). However, the promoting effects of exposure duration to LL on petiole and shoot elongation were affected by the developmental stages.

Plants at transitional stage showed higher elongation rate than those at juvenile and mature stages especially during the early period of the treatment (Fig. 3). Petioles of transitional plants were significantly longer only after 3 day exposure to LL, whereas the elongated petioles during the juvenile and mature stages were found after 6-9 d exposure to LL (Fig. 3A). Increase in plant height was shown from the sixth day in transitional plants whereas from the ninth day in juvenile and mature plants (Fig. 3B).

Statistically significant difference in petiole length between LL-exposed and control plants was made by more than about 20% and/or about 1.0 cm increase (derived from Fig. 3 and Table 1). We can estimate that the significant increases in petiole length were shown at about 4.3, 3.1, and 6.8 days after being exposed to LL in juvenile, transitional, and mature plants, respectively, and plant height increased significantly from about 6.5, 4.7, and 7.1 days after LL treatment, respec-

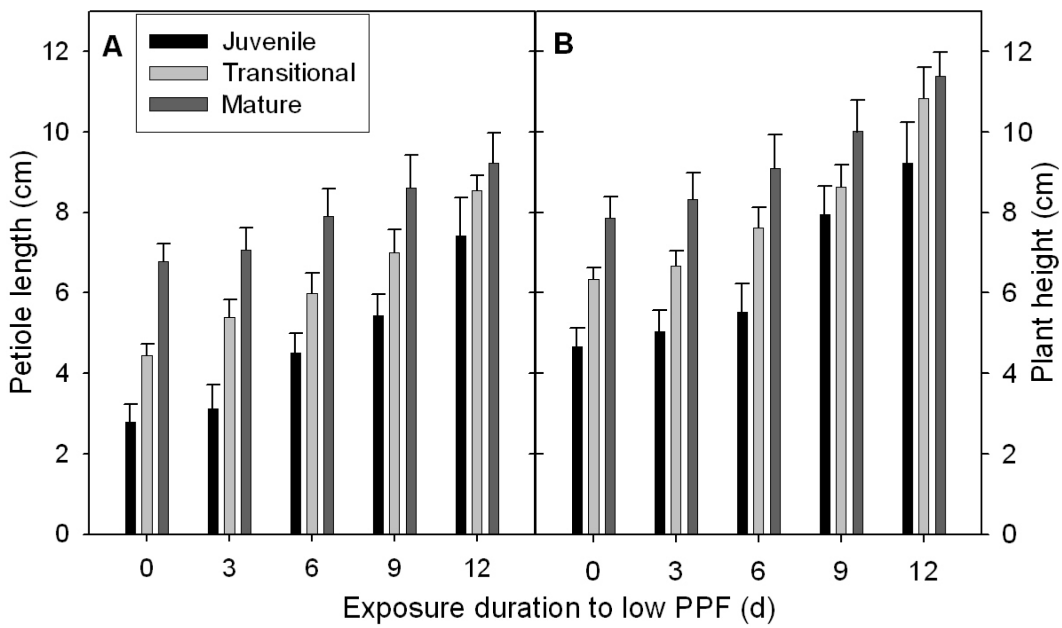

Fig. 3. Petiole length (A) and plant height (B) of *Cyclamen persicum* 'Metis Scarlet Red' at different developmental stages as influenced by exposure duration to low light. Plants were exposed to low light (60±5 μmol·m^{-2}·s^{-1} PPFD) for 0, 3, 6, 9, or 12 days and transferred to a high light (240±20 μmol·m^{-2}·s^{-1} PPFD) module in a chamber at 22/18°C (day/night) for 3 weeks. Plants reached at juvenile (with 5-6 unfolded leaves), transitional (with 1-3 visible flower buds), and mature stage (with 1-3 elongating peduncles) at the beginning of this experiment, respectively. Error bars represent 95% confidence intervals.

Table 1. Parameters of the quadratic regression analysis relating exposure duration (x) to low light (60 μmol·m^{-2}·s^{-1} PPFD) for petiole lengthz and plant height^z in *Cyclamen persicum* 'Metis Scarlet Red' at different developmental stages.

Developmental stage	y_0	a	b	R^2	*P*
		Petiole length			
Juvenile	2.75	0.11	0.023	0.95	0.0096
Transitional	4.54	0.18	0.013	0.96	0.0089
Mature	6.71	0.16	0.0043	0.93	0.0126
		Plant height			
Juvenile	4.60	0.046	0.030	0.84	0.0310
Transitional	6.36	0.0072	0.030	0.97	0.0059
Mature	7.87	0.11	0.015	0.99	0.0007

^{z}Petiole length (cm) or plant height (cm) = $y_0 + ax + bx^2$.

tively. There was a slight difference between petiole length and plant height because plant height is affected by the lengths of leaf petiole and lamina and the gradient between them.

Exposure time to low irradiance under different temperatures

Petiole length and plant height increased in proportion to exposure duration to low irradiance at all temperatures (Fig. 4). At each temperature, petiole length and plant height were quadratically correlated to exposure duration to LL (Table 2). However, the promoting effects of LL on the elongation rates of petiole and shoot changed depending on temperature. Petiole length was significantly longer at only 3 d after LL exposure at HT or MT, whereas significantly elongated petioles were found after 6-day LL exposure at LT (Fig. 4A). Significant increase in plant height was shown from the third day at HT but from the sixth day at LT or MT (Fig. 4B).

Statistically significant difference in petiole length between LL-exposed and control plants was made by more than about 20% and/or about 1.0 cm increase (derived from Fig. 4A and Table 2). From these results, we can assume that the significant increase of petiole length started to occur at about 4.7, 3.5, and 2.2 day after LL exposure to LT, MT, and HT, respectively, and plant height significantly increased from about 5.4, 4.7, and 3.3 days after LL treatment, respectively. HT treatment increased petiole length without LL

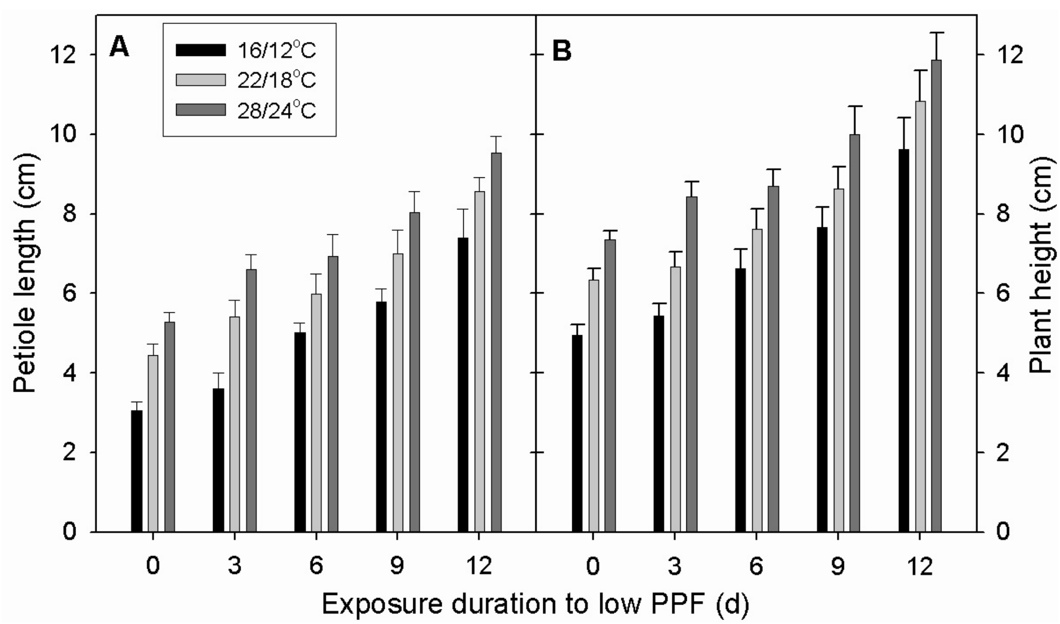

Fig. 4. Petiole length and plant height of *Cyclamen persicum* 'Metis Scarlet Red' grown under different temperatures as influenced by exposure duration to low light. Plants were exposed to low light (60±5 μmol·m^{-2}·s^{-1} PPFD) for 0, 3, 6, 9, or 12 days and transferred to a high light (240±20 μmol·m^{-2}·s^{-1} PPFD) module in each chamber at 16/12oC (LT), 22/18°C (MT), or 28/24°C (HT) (day/night) for 3 weeks. Error bars represent 95% confidence intervals.

Table 2. Parameters of the quadratic regression analysis relating exposure duration (x) to low light (60 μmol·m^{-2}·s^{-1} PPFD) for petiole lengthz and plant height^z in *Cyclamen persicum* 'Metis Scarlet Red' grown under different temperatures.

Temperature (℃) (day/night)	y_0	a	b	R^2	*P*
			Petiole length		
16/12	3.02	0.22	0.012	0.95	0.0101
22/18	4.54	0.18	0.013	0.96	0.0089
28/24	5.46	0.23	0.0087	0.87	0.0256
			Plant height		
16/12	4.95	0.12	0.022	0.97	0.0042
22/18	6.36	0.0072	0.030	0.97	0.0059
28/24	7.53	0.10	0.021	0.89	0.0218

^{z}Petiole length (cm) or plant height (cm) = $y_0 + ax + bx^2$.

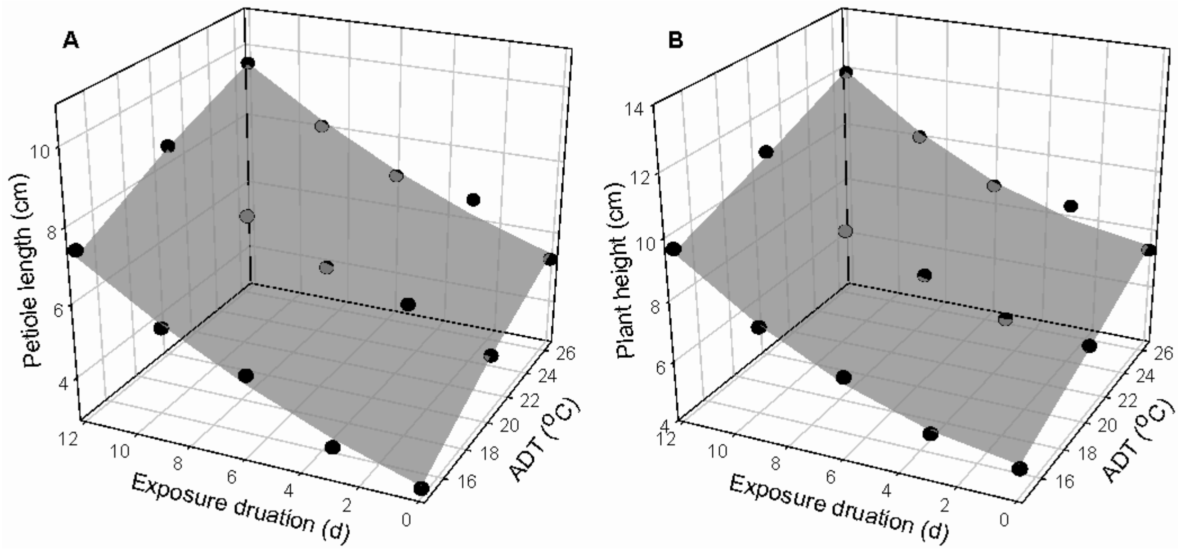

Fig. 5. Measured (black circles) and predicted (gray planes) petiole length (A) and plant height (B) for varying combinations of average daily temperature (ADT) and exposure duration to low PPFD (D_{LL}) in *Cyclamen persicum* 'Metis Scarlet Red'. These data were derived from Fig. 4. Petiole length (cm) = -1.337 + 0.368 ADT + 0.206 D_{LL} − 0.004 ADT^2 +0.011 D_{LL}^2 (R2 = 0.94, P < 0.0001); Plant height (cm) = 2.719 + 0.142 ADT + 0.076 D_{LL} + 0.001 ADT^2 +0.024 D_{LL}^2 (R^2 = 0.95, P < 0.0001).

exposure by 73% or 2.2 cm compared with LT and its increase at MT also reached 45% or 1.4 cm (Fig. 4A).

Petiole length and plant height quadratically increased with increasing average daily temperature (ADT) and LL exposure duration (D_{LL}) (Fig. 5). There were strong relationships between petiole length, ADT and D_{LL} (R^2 = 0.94, P < 0.0001) and between plant height, ADT and D_{LL} (R^2 = 0.95, P < 0.0001). Equations of petiole length (cm) = -1.337 + 0.368 ADT + 0.206 D_{LL} − 0.004 ADT^2 + 0.011 D_{LL}^2 and plant height (cm) = 2.719 + 0.142 ADT + 0.076 D_{LL} + 0.001 ADT^2 +0.024 D_{LL}^2 showed that 3-day LL exposure had the similar effect to temperature increase of 5.27℃ and 5.49℃ in petiole length and plant height, respectively. In this experiment, there was little interaction between ADT and D_{LL} so that petiole length and plant height were almost linearly correlated to ADT.

Discussion

Most plants generally show promoted shoot elongation and leaf expansion when they are exposed to low irradiance. Internode and leaf size increase with decreasing light intensity or increasing shading rate. These shade avoidance responses have been reported in *Brassica* (Potter et al., 1999), *Stellaria* (Kurepin et al., 2006), patato (Gawronska et al., 1995), Kentucky bluegrass (Tan and Qian, 2003), cherimoya (Higuchi et al., 2001), tall fescue (Allard et al., 1991), *Phaseolus vulgaris* (Knecht and O'leary, 1972), garlic (Rahim and Fordham, 1991), peach (Nii and Kuroiwa, 1988), five major tropical root crops (Onwueme and Johnston, 2000), and so on.

In Experiment I, shoot elongation of cyclamen was influenced by the time and duration exposed to low irradiance (Fig. 2). Petiole length and plant height increased with increasing exposure duration to LL and the elongation rate increased as the exposure time was later. Cyclamen plants had 5-6 leaves (juvenile stage) at the beginning of this experiment and 1-2 visible buds (transitional stage) at 3 weeks after treatment. In Experiment II, plants at the transitional stage were more sensitive to LL treatment with the same duration especially within 6 days after LL treatment (Fig. 3).

Cyclamen has a sigmoid growth pattern in plant height and the number of leaves and flower buds (Nakayama, 1977; Sundberg, 1981a, 1981b, 1982; Tsurushima, 1969). Widmer and Ryons (1985) identified two growth phases of commercial cyclamen. Phase I is vegetative and extends until the plant has 5-8 leaves. In this lag phase from seeding to floral initiation, plants slowly unfold leaves and elongate petioles. Phase II is vegetatively and generatively combined and lasts indefinitely. In this phase, plants drastically initiate and develop leaves and flower buds.

However, leaf initiation rate becomes slow because of the shortage of the space at the apical dome on corm where new leaf primordia can be formed (Sundberg, 1982). Phase II can be divided into two sub-phases; phase II-1, a transitional stage, is when plants exponentially initiate leaf and flower buds, whereas phase II-2, a mature stage, is when leaf and flower bud initiation becomes slower, and leaves and flowers grow up rapidly. Cyclamen plants must expend a considerable proportion of its energy towards corm enlargement as well as the growth of new leaves and flowers at phase II-2. Therefore, leaf (petiole) elongation and unfolding rates are highest at the transitional stage (phase II-1). Plants in this stage may sensitively respond to environmental changes such as decrease in light intensity and increase in temperature.

At the onset of Experiment I, plants with 5-6 fully unfolded leaves slowly unfolded leaves and elongated petioles. From the third week, they reached the phase II-1, grew more rapidly and responded more sensitively to low irradiance, resulting in longer petioles. Seedlings of *Brassica napus* (Potter et al., 1999) and *Stellaria longipes* (Kurepin et al., 2006) showed increase in plant height at the seventh day and shoot elongation rate at the fourth day, respectively. Reduced irradiance increased leaf length at the tenth day in *Allium sativa* (Rahim and Fordham, 1991) and decreased dry weight at the first week in tomato seedlings (Hamamoto et al., 2000).

Therefore, morphological changes by reduced irradiance start to occur at different time depending on light level, temperature, developmental stage, light condition exposed previously, genotype, and so on. In this study, it is assumed that exposure to low irradiance of 60 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for less than 1 week could promote petiole elongation of cyclamen during the transitional stage.

The number of leaves increased as the exposure duration to LL decreased (data not shown). In other words, increasing cumulative irradiance increased leaf number. Oh et al. (2009) reported that the number of leaves increased by about 20 as daily light integral (DLI) received for 16 weeks increased from 1.44 to 17.28 $mol \cdot m^{-2} \cdot d^{-1}$. In this study, there was a significant difference in leaf number although treatment duration was shorter and DLI difference between the highest and the lowest was smaller (data not shown). These data indicate that light reduction at the vigorous developmental stage causes potted cyclamen with over-elongated and fewer leaves.

Many researchers have reported that high temperature promoted elongation growth in many plant species. Higher temperature increased leaf length considerably in the tall genotype of wheat (Pinthus et al., 1989; Tonkinson et al., 1997). In *Lablab purpureus* (Kim and Okubo, 1996) and purple nutsedge (Sun and Nishimoto, 1999), plant height increased by more than four times with increasing temperature from 20℃ to 30℃. Temperature increase from 17/12℃ to 32/27℃ promoted stem elongation of Carrizo citrange seedlings by eight times (Vidal et al., 2003). These promoting effects were reported to attribute to increase in endogenous active GAs by high temperature.

Reports on the interaction of temperature and irradiance to elongation growth are equivocal. High temperature and low irradiance increased stem length independently in *Sandersonia aurantiaca* (Davies et al., 2002), potato (Menzel, 1985), and wheat (Pinthus and Abraham, 1996). It is difficult to derive a general trend from these previous studies because the optimum level of temperature and irradiance is different among plant species and the levels used in each study were various.

Our study indicates that low irradiance and high temperature promote leaf petiole elongation and lamina expansion with a little interaction each other and such promoting effects of low irradiance on petiole elongation increase under high temperature and at transitional stage in 'Metis Scarlet Red' cyclamen. In reality, petiole elongation is logically considered to be controlled by the changes of endogenous GA contents which increase under low irradiance and high temperature.

The data from this study suggest that cyclamen plants could immediately respond to reduced irradiance under higher temperature. On the contrary, compact cyclamen with short petioles can be obtained by decreasing temperature or exposure duration to low irradiance. Therefore, cyclamen growers must focus their attention to irradiance changes in greenhouse especially at the transitional stage and take suitable actions against reduced irradiance including supplemental lighting, ventilation, application of growth retardants, control of watering and fertilization, etc.

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저광도에 대한 시클라멘 엽병의 발육 단계 및 온도 조건별 신장 반응

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초 록. 낮은 광도는 시클라멘(*Cyclamen persicum* Mill.)의 지상부 신장을 촉진하여 분화의 품질을 떨어뜨리는데, 그 정도는 발육단계와 환경요인에 따라 달라지는 것으로 보인다. 저광도에 대한 엽병의 신장 반응 양상을 알아보기 위해, 유년상(전개엽 5-6매), 전이상(화아 1-3개) 및 성년상(화경 신장 중인 화아 1-3개)의 'Metis Scarlet Red' 시클라멘을 선별하여 명기/암기의 온도가 16/12(저온, LT), 22/18(중온, MT), 28/24°C (고온, HT)로 유지되는 대형 생장상의 생장 모듈 내에서 생장시켰다. 생장 모듈은 명기 동안 두 가지 광도조건[60(저광, LL), 240(고광, HL) $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD]으로 유지되었다. 실험 I에서는 MT 생장상에서 유년상의 식물체를 LL 또는 HL 모듈에 4주 동안 계속 두거나 처리 1, 2, 3주후 다른 광도의 모듈로 상호 이동시킨 후 신장 반응을 조사하였다. 실험II에서는 MT 생장상에서, 유년상, 전이상, 그리고 성년상의 식물체를 LL 모듈에 넣은 지 0, 3, 6, 9, 12일째에 HL 모듈로 옮기고 21일째에 신장 반응을 조사하였다. 실험 III에서는 LT, MT, HT 생장상에서 전이상의 식물체를 LL 모듈에 넣은 지 0, 3, 6, 9, 12일째에 HL 모듈로 옮기고 21일째에 신장 반응을 조사하였다. LL 노출시간이 0-4주까지 또는 0-12일까지 증가할수록 엽병장과 초장은 모든 온도 조건과 발육단계에서 증가하였다. 4주간 처리된 실험 I에서 후기의 LL 노출이 전기의 노출보다 엽병의 신장속도를 증가시켰다. 실험 II에서, 처리기간 12일 중 초기의 엽병 신장 양상을 보면 전이상 식물체가 유년상이나 성년상보다 LL에 더 민감하게 반응하였다. 실험 III에서, 온도가 증가할수록, 그리고 LL노출시간이 길어질수록 시클라멘의 엽병장은 증가하였다. HT에서의 엽병 신장 속도는 LT와 비교하여 LL처리 초기부터 빠르게 증가하였다. 엽병 신장에 있어서 온도 6°C 증가는 3일간 LL 노출과 유사한 효과를 보였다. 결론적으로, 시클라멘은 전이상일 때 고온 하에서 더 즉각적으로 저광도에 반응하여 엽병을 신장시킨다는 것을 알 수 있었다.

추가 주요어 : 초장 조절, 광도, 분화 생산, 음지 회피, 줄기 신장