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Increasing Duration and Intensity of Supplemental Lighting during Nighttime to Promote Growth and Photosynthesis in *Cymbidium* Plants

야간 보광 시 광도와 주기에 따른 생육과 광합성 반응

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SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL OF
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ABSTRACT

These studies were conducted to investigate the influence of supplemental lighting timing in a day (Expt. 1), and to determine how the duration and light intensity during nighttime supplemental lighting (NSL) influence the growth and photosynthesis of the *Cymbidium* plants (Expt. 2). Nine-month-old *Cymbidium* 'Yang Guifei' and 'Wine Shower' plants were treated with three different supplemental lighting timings: from 22:00 to 02:00 $_{HR}$ (middle of the night, MN); from 17:00 to 21:00 $_{HR}$ (day extension, DE); and from 07:00 to 09:00 $_{HR}$ plus from 17:00 to19:00 $_{HR}$ (day extension which was divided

into two sections, 1/2DE), and with non-supplemental lighting (8/16 h; short day, SD) for 4 months. All of the supplemental lighting treatments were provided by 100% red LEDs (peak at 640 and 660 nm) with 150 μmol·m^{-2}·s^{-1} and 800 μmol·mol^{-1} of CO_2 was supplied during nighttime. In both cultivars, pseudobulb diameter under supplemental lighting treatments (MN, DE, and 1/2DE) appeared to be greater irrespective of supplemental lighting timings than under SD. Photosynthetic assimilation rate (A_n) also showed the similar response as growth. These results indicate that supplemental lighting timing application is not required for promoting growth and photosynthesis in these two *Cymbidium* plants. Furthermore, to accelerate growth and photosynthesis of *Cymbidium* plants, it is related with the total light integral. Thus, in Expt.2, 2-month-old *Cymbidium* plants with the same cultivar in Expt. 1 were used to determine how NSL duration and light intensity, which affects NSL light integral, influence growth and photosynthesis. Plants were treated with five NSL durations of 2, 4, 6, 8, and 16 h and three light intensities of 10, 100, and 200 μmol·m^{-2}·s^{-1} for 4 months, which provided 13 NSL light integrals ranging from 0 to 11.52 mol·m^{-2}·d^{-1}. After 4 months of NSL treatment, plants in all treatments were then grown in the same ambient photoperiod to identify the residual effects on subsequent growth. In both cultivars, pseudobulb diameter, number of leaves, leaf width, and biomass accumulation significantly increased as NSL duration and light intensity increased. In case of pseudobulb diameter, it increased by 33% and 43% in 'Yang Guifei' and 'Wine Shower', respectively, as NSL light integral increased from 0 to 11.52 mol·m^{-2}·d^{-1}. However, relative chlorophyll content (SPAD value) significantly decreased in 'Yang Guifei' by increasing NSL light integral during NSL treatment but, it recovered after the treatments ended. A_n during NSL treatment was promoted according

to the increase of NSL duration and light intensity in both cultivars. Also, daily A_n was increased with increasing NSL light integral and showed positive correlation with pseudobulb diameter. These experiments indicate that supplemental lighting during nighttime with high light integral accelerates growth with greater photosynthetic assimilation rate.

Additional keywords: orchid, vegetative growth, daily light integral

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INTRODUCTION

Flowering orchids including *Cymbidium*, *Phalaenopsis*, and *Dendrobium* has become one of the largest segments of floriculture crops worldwide (Lopez and Runkle, 2005). Flowering orchids are marketed globally because of diverse flower colors, unique floral structure, and flower longevity (Chen and Chen, 2011; De et al., 2014). They are widely used as cut flowers for corsages and flower arrangements; as potted flowering plants; and as hanging baskets, and *Cymbidium* plants are also used as herbal medicines (De et al., 2014; Lopez and Runkle, 2005).

Commercially producing orchids are mostly slow-growing plants. *Cymbidium* requires at least 5 years from sowing to flower development, including 3 to 4 years of vegetative growth (Hew and Yong, 2004; Kim et al., 2011). Vegetative growth includes the juvenile stage; early phase of plant growth, where flowering cannot be induced by any treatment (Hew and Yong, 2004). Therefore, *Cymbidium* passes through several winter seasons during cultivation. During winter season, plants are exposed to lower range of photosynthetic daily light integrals (DLI) as an average of 2.5 to 12 $mol \cdot m^{-2} \cdot d^{-1}$, depending on greenhouse location and shading from greenhouse structures (Korczynski et al., 2002; Moccaldi and Runkle, 2007). The mean DLI during winter season can be a limited factor to accelerate *Cymbidium* vegetative growth in many greenhouses. In the northern European greenhouse, the use of electricity for supplemental lighting increases to increase plant production (Markvart et al., 2009).

Numerous reports have described that higher DLI by day-extension (DE) promoted shoot and root growth, and biomass accumulation resulting improvement of final plant quality in many floricultural crops such as *Cyclamen* (Oh et al., 2009), new guinea

impatiens and petunia (Lopez and Runkle, 2008), and marigold, salvia and zinnia (Faust et al., 2005), *Campanula* and *Lupinus* (Calvin and Dole, 2001). Nemali and van Iersel, (2004) also reported that high DLI can increase growth rates by promoting photosynthesis. Increasing DLI with a night interruption (NI) increased biomass accumulation in *Cymbidium* (Kim et al., 2011). Four hours of NI with 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$ promoted vegetative growth by increasing pseudobulb diameter and number of leaves. This increased growth rates contributed to the acceleration in flowering compared to non-supplemental lighting (ambient light; 9/15 h). However, Dodd et al. (2005) suggested that correct matching of the plant circadian clock with the environmental period positively influences net photosynthesis. NSL might have an adverse effect on photosynthesis because of its abnormal artificial light at midnight, compared to day extension (DE).

To our knowledge, the comparison of growth and photosynthesis of using supplemental lighting by DE and NSL has not been examined in *Cymbidium*. It is not known to what degree NSL might affect the photosynthesis and subsequent growth. Overall, previous studies showed that increasing DLI promoted growth by enhancing photosynthesis. Therefore, the objectives of this studies were 1) to evaluate efficiency of different supplemental lighting timing in a day in photosynthesis and growth, and 2) to determine how NSL light integral affects growth and photosynthesis in *Cymbidium* young plants.

LITERATURE REVIEW

Characteristics of *Cymbidium*

Cymbidium belongs in the family of Orchidaceae which is one of the largest families of flowering plants (Arditti, 1992). *Cymbidium* contains approximately 44 species. Most of *Cymbidium* are native throughout the Himalayas and tropical regions of the Southeast Asia to Australia (Pridgeon, 2000). Because *Cymbidium* is widely distributed, they are divided into three different horticulture groups depending on their temperature tolerance: cool, intermediate, and warm (Kim et al., 2011; Lopez and Runkle, 2005). Photosynthetic activity of *Cymbidium* is classified into strong crassulacean acid metabolism (CAM), weak CAM, and C_3 on the basis of CAM activity (Motomura et al., 2008). The epiphytic and lithophytic species expresses as the CAM activity, while the terrestrial species always exhibit C_3 metabolism. Most commercially cultivated *Cymbidium*s are temperate *Cymbidium* with terrestrial form.

Pseudobulb of *Cymbidium*

Pseudobulb is a storage organ with enlarged stems. These specialized structure has ability to store water, mineral, and carbohydrates and it is to be a central importance in the growth and development of orchids (Ng and Hew, 2000). The ability of orchid pseudobulbs in photosynthetic points is that pseudobulb roles as a carbon source for plant. In *Cymbidium*, pseudobulb accumulates massive amounts of carbohydrates during vegetative development (Kim et al., 2013a). These carbohydrate reserves are subsequently remobilized to support new shoot and inflorescence development (Hew and Ng. 1996). Thus, nowadays the juvenility based on pseudobulb diameter was suggested in some studies (Kim et al., 2011; Blanchard and Runkle, 2008; Ichihashi, 1997). In

Cymbidium, they must reach a certain pseudobulb size to attain the capacity to flower. Kim et al. (2011) reported that *Cymbidium* has a minimum pseudobulb diameter requirement for inflorescence initiation which is diverse according to cultivars. Examples were; 4.4 cm for *Cymbidium* 'Yokihi' and 5.2 cm for 'Red Fire'. Before requiring a certain pseudobulb size, plants are insensitive to conditions that promote floral initiation (Bemier et al., 1981). If a plant is prematurely exposed to reproductive conditions before end of the juvenile stage, plant may not be able to support quality flowers and thereby decrease the uniformity of flowering (Cameron et al., 1996).

Growth Affected by Supplemental Lighting

During periods of poor light environments such as winter season, artificial lighting can increase photosynthesis and plant growth in many floriculture crops. Extending daylength by high light intensity of supplemental lighting resulted in an increase of shoot, root growth, and biomass accumulation in lettuce (Martineau et al., 2012), *Petunia* and *Impatiens* (Adams et al., 2008), *Campanula* and *Lupinus* (Calvins and Dole, 2001), *Cyclamen* (Oh et al., 2013), and *Cymbidium* (Kim et al., 2011). In *Cymbidium*, 4 h of nighttime supplemental lighting (NSL) with 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$ promoted pseudobulb diameter and number of leaves. Along with the promotion of the vegetative growth, the flowering has been enhanced. These results were also shown in *Cyclamen* (Oh et al., 2009), due to higher daily light integral (DLI) caused by extended daylength and high light intensity. The increase growth rate by high DLI was derived from enhanced photosynthesis (Nemali and van Ieresel, 2004).

MATERIALS AND METHODS

Supplemental Lighting Timing in a Day (Experiment 1)

Plant and growth conditions. Nine-month-old *Cymbidium* hybrids 'Yang Guifei' and 'Wine Shower' (Mukoyama Orchids Co., Ltd., Yamanashiken, Japan) plants were transplanted into 12 cm pots filled with 100% bark. The plants were purchased from a commercial grower (Hae Pyeung Orchids, Gongju, Republic of Korea) at 2-month-old stage and acclimated for 7 months in the university farm (Seoul National University, Suwon, Republic of Korea). Average temperature inside the greenhouse was 26 and 24°C, day and night, respectively. Photoperiod was provided with natural daylength with mean photosynthetic photon flux density (PPFD) of 312 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and additional supplemental lighting was provided with high-pressure sodium (HPS) lamps (SKL-01; GEO, Hwasung, Republic of Korea) from 9:00 to 10:30 $_{HR}$ and from 15:30 to 17:00 $_{HR}$ during winter season (from Dec. to Apr.) because of low light intensity. Plants were irrigated daily with tap water using a sprinkler. Additionally, water soluble fertilizers (EC 1.0 mS·cm-1; Technigro 20N-9N-20K, Sun-Gro Horticulture, Bellevue, WA, USA) were applied once a week. Four grams of slow release fertilizers (11N-4.4P-15.7K+1.2Mg+TE, Everris Co., Geldermalsen, The Netherlands) were also placed at the top of the substrate. Pesticides were applied at their recommended rates as needed throughout the growing period.

Supplemental lighting treatment. *Cymbidium* plants of uniform size were then moved to a controlled environment plant production system maintained at 20°C, to identify growth by supplemental lighting timing a day. Plants were treated with three different supplemental lighting timing in a day at from 22:00 to 02:00 $_{HR}$ (middle of the

night, MN), from 17:00 to 21:00 $_{HR}$ (day extension, DE), and from 07:00 to 09:00 $_{HR}$ plus from 17:00 to 19:00 $_{HR}$ (day extension which was divided into two sections, 1/2DE), and with non-supplemental lighting (8/16 h photoperiod; short day, SD) (Fig. 1). Among the three different supplemental lighting timing in a day treatments, daily light integral (DLI) was set the same to determine the growth by DE and NSL. All of supplemental lighting was provided by 100% red LEDs (Stec LED C., Paju, Republic of Korea). Red LEDs used in this study peaks at 640 and 660 nm (Fig. 2) as measured with a spectrometer (Stellar Net, Tampa, FL, USA) because chlorophyll a and b effectively absorbs energy around at 675 and 640 nm, respectively (French et al., 1972). A daytime lighting was average 350 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for 8 h, and 150 $\mu mol \cdot m^{-2} \cdot s^{-1}$ was provided during the supplemental lighting timing in a day. Atmospheric CO_2 concentration in the controlled environment plant production system was applied at 400 and 800 $\mu mol \cdot mol^{-1}$, day and night, respectively. The supplemental lighting treatments were treated from 14 Jul. 2017 to 3 Nov. 2017, for 4 months.

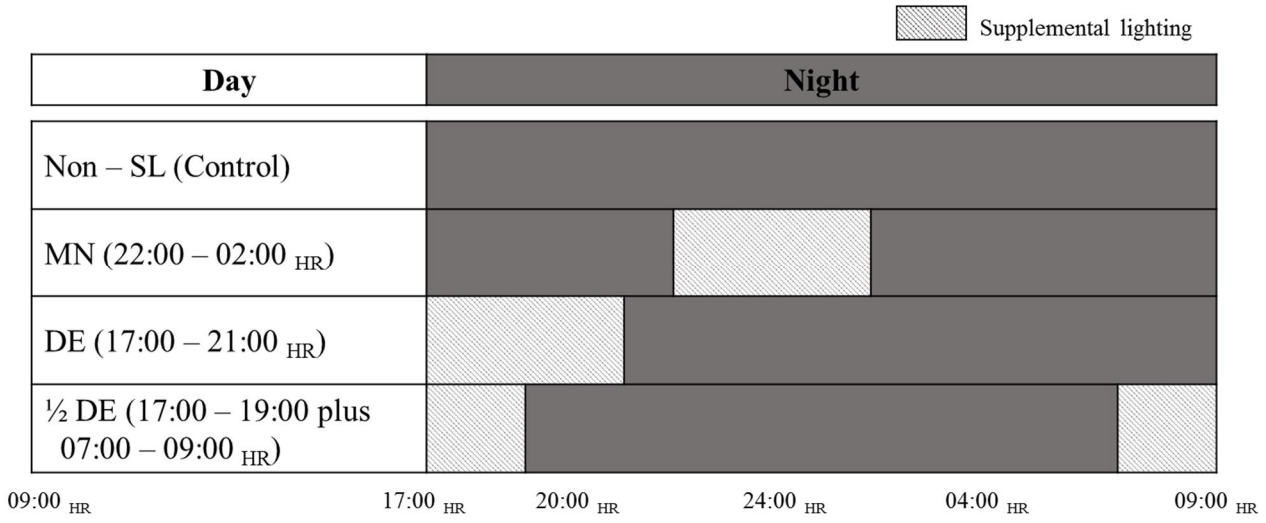

Fig. 1. Schematic diagram of supplemental lighting timing in a day used in this study. Plants were grown under short day with non-supplemental lighting (SD) and 4 h of different supplemental lighting timing in a day; middle of the night (MN), day extension (DE), and DE which was divided into two sections (1/2DE).

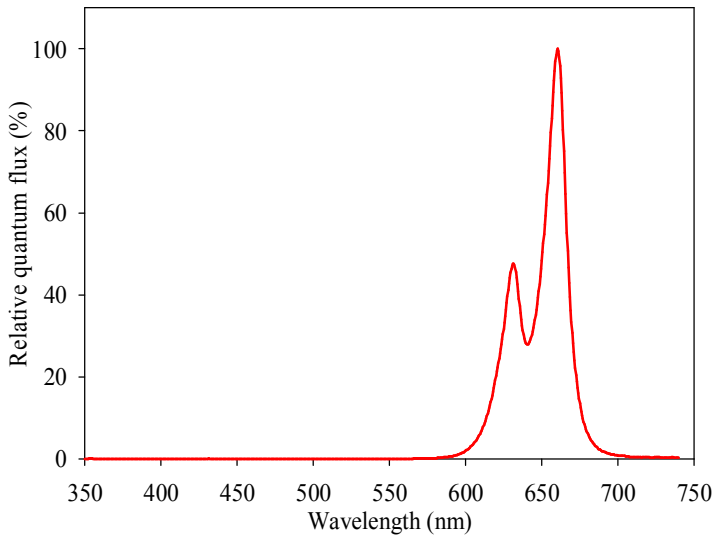

Fig. 2. Relative spectral distribution of light emitted by red light-emitting diodes (LEDs) used in this study.

Measurement. Pseudobulb diameter, number of leaves, leaf length, and width were measured by monthly during the experimental period. Pseudobulb diameter was measured at the widest point of pseudobulb using a digital vernier caliper (ABS Digimatic Caliper; Mitutoyo Co., Ltd., Tsukuba, Japan). The longest leaf measured from the base of pseudobulb was used to represent leaf length. Dry weights of leaves, pseudobulbs and roots were measured after drying in a dry oven at 80°C for 7 days after 4 months of treatment.

Relative chlorophyll content of the third mature leaf from the top was measured using a SPAD meter (SPAD 502, Konica Minolta Sensing Inc., Sakai, Osaka, Japan) monthly during 4 months of treatment.

Net photosynthetic assimilation rate (A_n) of leaf was measured in both *Cymbidium* 'Yang Guifei' and 'Wine Shower' plants after 14 weeks of treatment using a portable photosynthesis system (Li 6400, Li-Cor Co., Inc., Lincoln, NE, USA) equipped with an infrared gas analyzer. Three plants per treatment were randomly chosen and used for the measurement. Third mature leaf from the top was clamped on to a 6 cm^2 clear top head chamber. Stomatal ratio was input to be 1 because *Cymbidium* is a monocotyledon with the equal stomata density on top and bottom. Relative humidity in the leaf chamber was 60%. Temperature was kept at 20°C during the day and night, respectively. CO_2 concentration in inside the leaf chamber was maintained at approximately 400 and 800 $\mu mol \cdot mol^{-1}$ during day and night, respectively. A_n were measured every hour for 5 minutes for 24 hours. Daily A_n was calculated from the A_n data.

Duration and Intensity of Supplemental Lighting during Nighttime (Experiment 2)

Plant and growth conditions. Two-month-old *Cymbidium* hybrid 'Yang Guifei' and 'Wine Shower' (Mukoyama Orchids Co., Ltd., Yamanashiken, Japan) plants were purchased from a commercial grower (Hae Pyeung Orchids, Gongju, Republic of Korea) and transplanted into 8 cm pots filled with 100% bark. Then, after 4 months of growth, plants were re-transplanted into 12 cm pots. The plants were acclimated to the same environmental conditions for 1 month in a university farm (Seoul National University, Suwon, Republic of Korea). Average temperature inside greenhouse was 25 and 22°C, day and night, respectively. Photoperiod was 8 h (from 9:00 to 17:00 $_{HR}$) controlled with black cloth, with natural sunlight at a mean PPFD of 312 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and additional supplemental lighting provided with HPS lamps (SKL-01; GEO, Hwasung, Republic of Korea) from 9:00 to 10:30 $_{HR}$ and from 15:30 to 17:00 $_{HR}$ during winter season (from Dec. to Apr.) because of low light intensity. Plants were irrigated daily with tap water using a sprinkler. Additionally, water soluble fertilizers (EC 1.0 $mS \cdot cm^{-1}$; Technigro 20N-9N-20K, Sun-Gro Horticulture, Bellevue, WA, USA) were applied once a week. Two grams of slow release fertilizers (11N-4.4P-15.7K+1.2Mg+TE, Everris Co., Geldermalsen, The Netherlands) were also placed on the top of the substrate. Pesticides were applied at their recommended rates as needed throughout the growing period.

NSL treatment. *Cymbidium* plants of uniform size were treated with five different NSL durations: 2 (from 23:00 to 01:00 $_{HR}$), 4 (from 22:00 to 02:00 $_{HR}$), 6 (from 21:00 to 03:00 $_{HR}$), 8 (from 20:00 to 04:00 $_{HR}$), or 16 h (continuous light, from 17:00 to 9:00 $_{HR}$)

(Fig. 3) and three different NSL light intensities: 10, 100, of 200 μmol·m^{-2}·s^{-1}, providing 16 NSL treatments. NSL light integrals ranged from 0 to 11.52 mol·m^{-2}·d^{-1}. All of NSL lighting was provided by 100% red LEDs (Stec LED C., Paju, Republic of Korea) which peaks at 640 and 660 nm (Fig. 2, identical to expt. 1) as measured with a spectrometer (Stellar Net, Tampa, FL, USA). During NSL treatment atmospheric CO_2 concentration in greenhouse was maintained at 400 and 800 μmol·mol^{-1}, daytime and nighttime, respectively. The NSL treatments were treated from 9 Dec. 2016 to 4 Apr. 2017, for 4 months. After the end of NSL treatment, all plants were grown in the same environmental condition to identify the residual effects on subsequent growth.

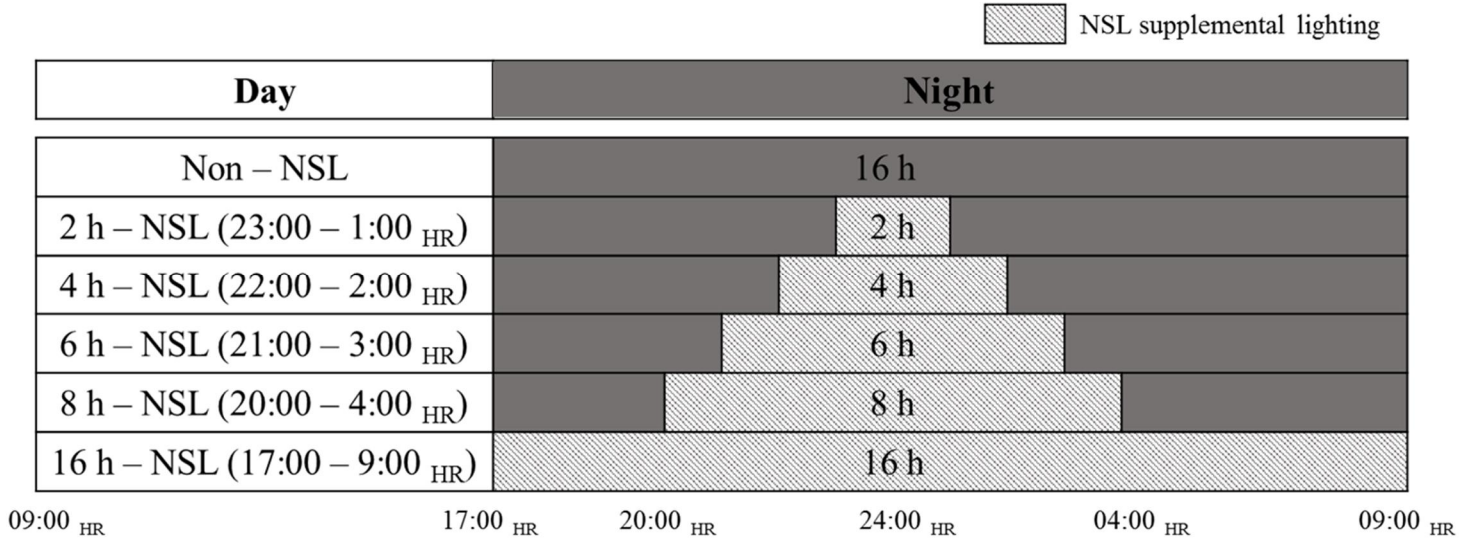

Fig. 3. Schematic diagram of nighttime supplemental lighting (NSL) duration treatment used in this study. Each duration was treated with three different light intensities of 10, 100, and 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Measurements. Pseudobulb diameter, number of leaves, leaf length, and width were measured monthly during the experimental period. Pseudobulb diameter was measured at the widest point of the pseudobulb using a digital vernier caliper (ABS Digimatic Caliper; Mitutoyo Co., Ltd., Tsukuba, Japan). The longest leaf measured from the base of the pseudobulb was used to represent leaf length. Dry weight of leaves, pseudobulbs and roots were measured after drying in a dry oven at 80°C for 7 days after the 4 months of NSL treatment.

Relative chlorophyll content of the third mature leaf from the top was also measured using a SPAD meter (SPAD 502, Konica Minolta Sensing Inc., Sakai, Osaka, Japan) monthly during 4 months of NSL treatment and also 1 month after the end of treatment to investigate the residual effect.

Net photosynthetic assimilation rate (A_n) of the leaf was measured in both *Cymbidium* 'Yang Guifei' and 'Wine Shower' plants after 2 months of NSL treatments using a portable photosynthesis system (Li 6400, Li-Cor Co., Inc., Lincoln, NE, USA) equipped with an infrared gas analyzer. Three plants per treatment were randomly chosen and used for the measurement. Third mature leaf from the top was clamped on to a 6 cm^2 clear top head chamber. Stomatal ratio was input to be 1 because *Cymbidium* is a monocotyledon with equal stomata density on top and bottom. Relative humidity in the head chamber was 60%.Temperature and CO_2 concentration inside the head chamber were kept at 25/20°C and 400/800 $\mu mol \cdot mol^{-1}$ during daytime and nighttime, respectively, the same value inside the greenhouse. A_n were measured every hour for 10 minutes for 24 hours. Daily A_n was calculated from the A_n data.

Statistical analysis. The experimental design was completely randomized design with 10 plants. Data were analyzed using the SAS system for Windows version 9.3 (SAS Inst. Inc., Cary, NC, USA). Differences among the treatment means were assessed by Duncan's multiple range test at $p < 0.05$. Regression and graph module analysis was performed using Sigma Plot software version 8.0 (Systat Software, Inc., Chicago, IL, USA). The regression was performed with a formula of '$f(x) = y_0 + ax + bx^2$'.

RESULTS and DISCUSSION

Supplemental Lighting Timing in a Day (Experiment 1)

Vegetative growth. Supplemental lighting accelerated growth in both cultivars of *Cymbidium* with regardless of supplemental lighting timing (Table 1 and Fig. 4). MN had no negative effect on growth compared with DE. Pseudobulb diameter was significantly ($p < 0.05$ and 0.01) greater under supplemental lighting treatments (MN, DE, and 1/2 DE) than under SD in both cultivars regardless of supplemental lighting timings (Table 1 and Fig. 4). Thus, plants grown under supplemental lighting appeared to be greater irrespective of supplemental lighting timing than under SD in both cultivars. Numerous researchers had found that supplemental lighting accelerated growth when the light environment was poor (Bredmose, 1993; Treder, 2003; Shin et al., 2010). Adams et al. (2008) suggested that 4 or 8 h of DE was more effective than 2 h of MN in impatiens. However, in this study duration of supplemental lighting was the same among the treatments with the same DLI. Markvart et al. (2009) and Park et al. (2013) reported that the application of supplemental lighting timing within same light integral had no statistical difference in growth. In case of *Dianthus*, number of nodes and plant height were higher in NI treatments compared to the SD, while no statistical differences were observed among the application of NI timings (Park et al., 2013).

Other growth parameters such as number of new bulbs, number of leaves, leaf length, leaf width, and chlorophyll contents had no statistical differences among the treatments in both cultivars (Table 1). Perhaps, these results were due to slow growth rate of *Cymbidium* which takes several years to flower (Hew and Yong, 2004). In Kim et al.

(2011) study, the rage of growth such as number of leaves, leaf length, and pseudobulb diameter were appeared much bigger among the treatments at the 2nd year of NI treatment. In this study, the growth rate of pseudobulb diameter was found to be linear ($r^2 > 0.90$ in all treatments in both cultivars) throughout the experimental period (Fig. 5). The slope of growth of pseudobulb diameter was observed more steeply in MN, DE, and ½DE than in SD in both cultivars. Although, the slope gradient between supplemental lighting treatments and SD were very small, if supplemental lighting treated longer, the difference is expected to be much greater.

Dry weight of pseudobulbs, leaves, and roots was measured after 4 months of treatment (Table 2). In 'Yang Guifei', dry weight was not significantly different among the treatments, however the value of peudobulbs weight was greater in supplemental lighting treatments compared to SD. In 'Wine Shower', dry weight of pseudobulbs and roots significantly ($p < 0.05$) increased among the treatments. The highest dry weight was observed in 1/2DE treatment. In *Chrysanthemum*, dry weight of stem and leaves was found to be not significantly different among the different application timings with same 5 h of supplemental lighting (Markvart et al., 2009). However, in this study, 'Yang Guifei' had no significant differences in dry weight among the treatments. Since *Cymbidium* needs more than 3 years of cultivation period, if supplemental lighting is provided for several years, the effect might be more distinct at the supplemental lighting treatments as seen on the slope of pseudobulb diameter growth (Fig. 5).

Table 1. Effect of supplemental lighting timing in a day on number of new leaves, pseudobulb diameter, number of leaves, leaf length, leaf width, and relative chlorophyll contents in SPAD readings in *Cymbidium* 'Yang Guifei' and 'Wine Shower' after 4 months of treatment

Treatment	No. of new bulbs	Pseudobulb diameter (mm)	No. of leaves	Leaf length (cm)	Leaf width (cm)	Chlorophyll content (SPAD)
			'Yang Guifei'			
SD[z]	1.1	23.11b[y]	17.5	51.0	1.8	45.6
MN	0.7	26.68a	19.3	47.4	1.8	44.7
DE	1.1	25.32a	17.4	47.2	1.8	45.5
1/2DE	1.0	25.42a	18.8	47.6	1.8	45.6
Significance	NS	*	NS	NS	NS	NS
			'Wine Shower'			
SD	1.2	27.31b	14.2	45.3	1.8	61.8
MN	1.5	29.88a	14.2	44.4	1.8	57.6
DE	1.7	29.05a	14.8	46.2	1.9	60.1
1/2DE	1.3	29.53a	14.1	45.8	1.8	55.3
Significance	NS	**	NS	NS	NS	NS

[z]Plants were grown under non-supplemental lighting (SD), supplemental lighting at middle of the night (MN), day extension (DE), and DE which was divided into two sections (1/2DE).
[y]Mean separation within columns by Duncan's multiple arrange test at $p < 0.05$.
[NS, *, **, ***]Non-significant, significant at $p < 0.05$, 0.01, or 0.001, respectively.

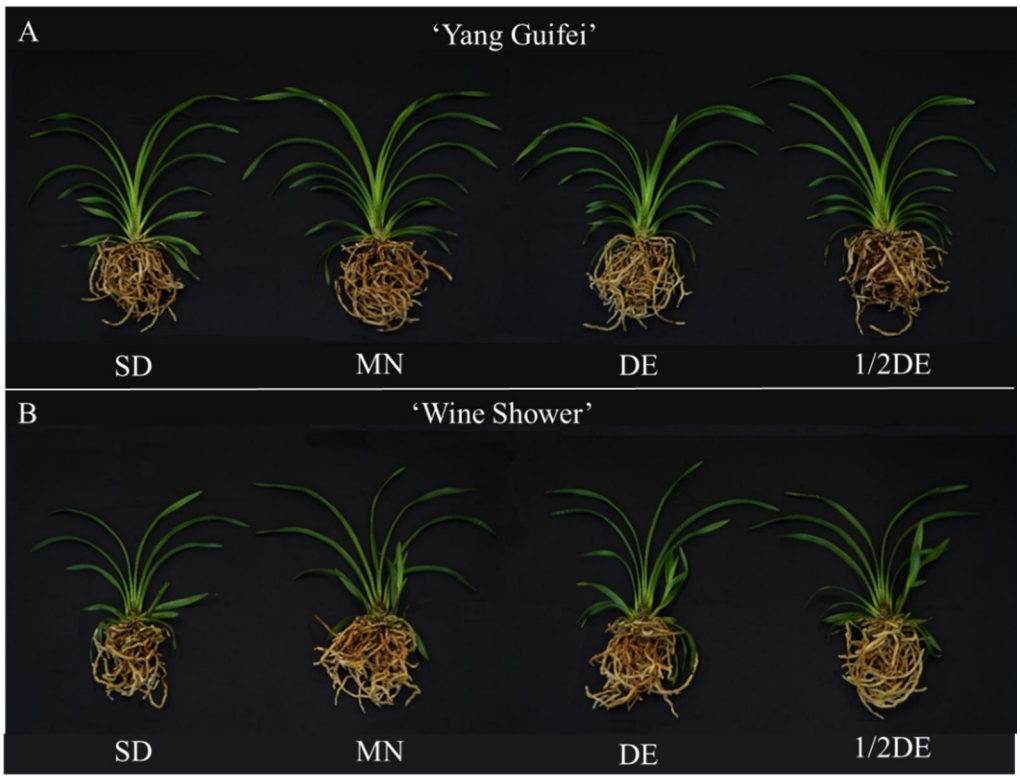

Fig. 4. Effect of supplemental lighting timing in a day on biomass characteristics of *Cymbidium* 'Yang Guifei' (A) and 'Wine Shower' (B) after 4 months of treatment. Plants were growth under short day with non-supplemental lighting (SD) and 4 h of different supplemental lighting timing in a day; middle of the night (MN), day extension (DE), and DE which was divided into two sections (1/2DE).

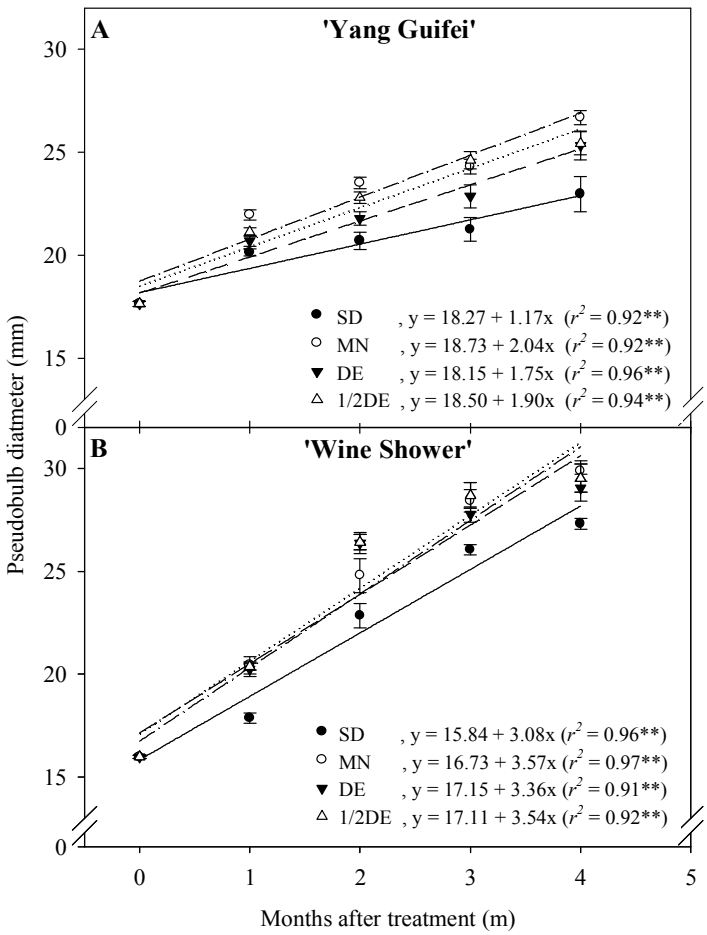

Fig. 5. Relationship between months after treatment and pseudobulb diameter of *Cymbidium* 'Yang Guifei' (A) and 'Wine Shower' (B). Plants were growth under short day with non-supplemental lighting (SD) and 4 h of different supplemental lighting timing in a day; middle of the night (MN), day extension (DE), and DE which was divided into two sections (1/2DE). Vertical bars represents means and ± S.E. (n=7). **Significant at $p < 0.01$.

Table 2. Effect of supplemental lighting timing in a day on dry weights of pseudobulbs, leaves, and roots in *Cymbidium* 'Yang Guifei' and 'Wine Shower' after 4 months of treatment

Treatment	Shoot		Root
	Pseudobulb	Leaf	
	'Yang Guifei'		
SD[z]	2.43[y]	3.54	6.37
MN	2.53	3.85	7.71
DE	2.55	3.39	7.36
1/2DE	2.53	4.08	7.47
Significance	NS	NS	NS
	'Wine Shower'		
SD	2.98b	3.17	6.29b
MN	3.06b	3.40	7.64ab
DE	3.33ab	3.45	6.59ab
1/2DE	3.53a	3.61	7.81a
Significance	*	NS	*

[z]Plants were grown under non-supplemental lighting (SD), supplemental lighting at middle of the night (MN), day extension (DE), and DE which was divided into two sections (1/2DE).
[y]Mean separation within columns by Duncan's multiple arrange test at $p < 0.05$.
[NS, *]Non-significant or significant at $p < 0.05$, respectively.

Photosynthetic assimilation rate. Net photosynthetic assimilation rates (A_n) in response to supplemental lighting timings were measured for 24 h after 14 weeks of treatment in both cultivars (Fig. 6). The 4 h of supplemental lighting had prolonged the photosynthetic period, regardless of application timings. Mean A_n was increased under nighttime of approximately 1.55 and 1.24 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$, compared with SD of -0.54 and -0.44 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$, in *Cymbidium* 'Yang Guifei' and 'Wine Shower', respectively. Therefore, supplemental lighting had effectively extended time for photosynthesis as a result of reduction period of dark respiration in *Cymbidium* as also mentioned by Xu et al. (2004) and Nemali and van Iersel (2004). Kim et al. (2015) also reported that NI with high light intensity increased growth, because it increased A_n during nighttime. Dodd et al. (2005) suggested that correct matching of the circadian clock period with that of the external light-dark cycle influenced postiviely in the photosynthesis. MN in this study which interrupts nightime by supplemental lighting might reset circadian rhythms and influence in photosynthesis. However, in this research the disadvantage of the interruption of daily rhythm by MN were not able to detect.

Daily A_n was observed by calculating the A_n, it significantly ($p < 0.001$) increased in supplemental lighting treatments compared with SD (Fig. 7). Daily A_n had no statistical differences among the application of supplemental lighting timings in both cultivars. Thus, photosynthetic behavior during MN might had not changed. Markvart et al. (2008) also reported that *Chrysanthemum* plants did not changed their photosynthetic behavior under different supplemental lighting timings. Since, the same DLI has been exposed under the supplemental lighting treatments, it is expected that carbohydrates from leaves which is fixed in photosynthesis might be same.

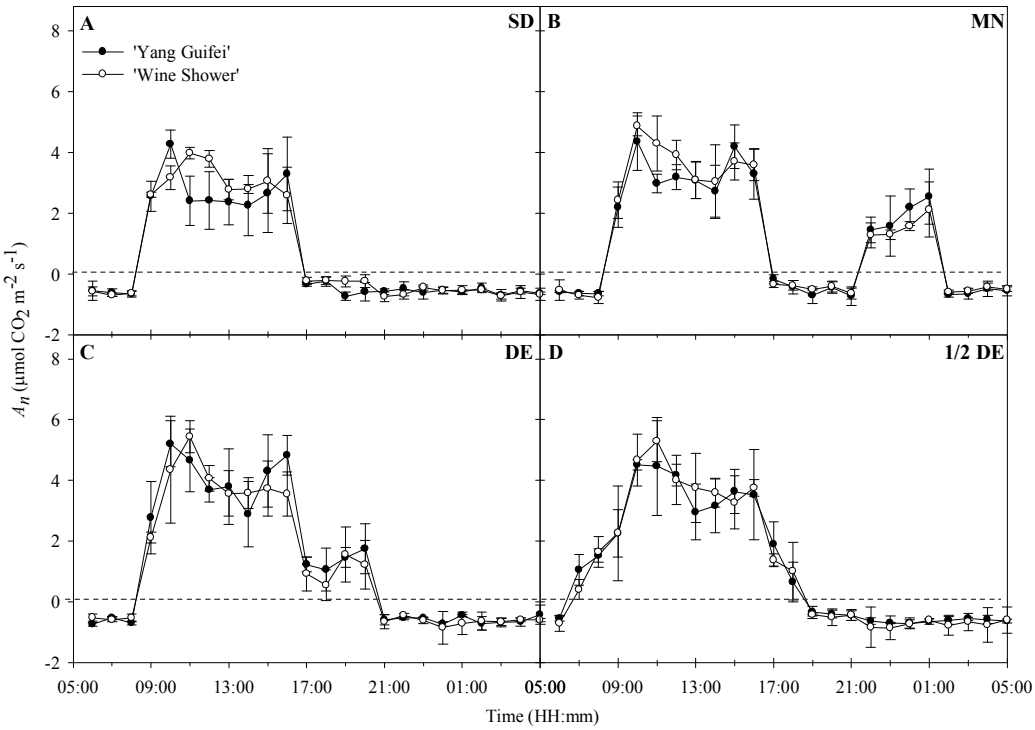

Fig. 6. Net photosynthetic assimilation rate (A_n) of *Cymbidium* 'Yang Guifei' and 'Wine Shower' by different supplemental lighting timing in a day of non-supplemental lighting (SD; A), supplemental lighting at middle of night (MN; B), day extension (DE; C), and DE which was divided into two sections (1/2DE; D). Measurements were taken after 14 weeks of treatment. Vertical bars represents means and ± S.E. (n=3).

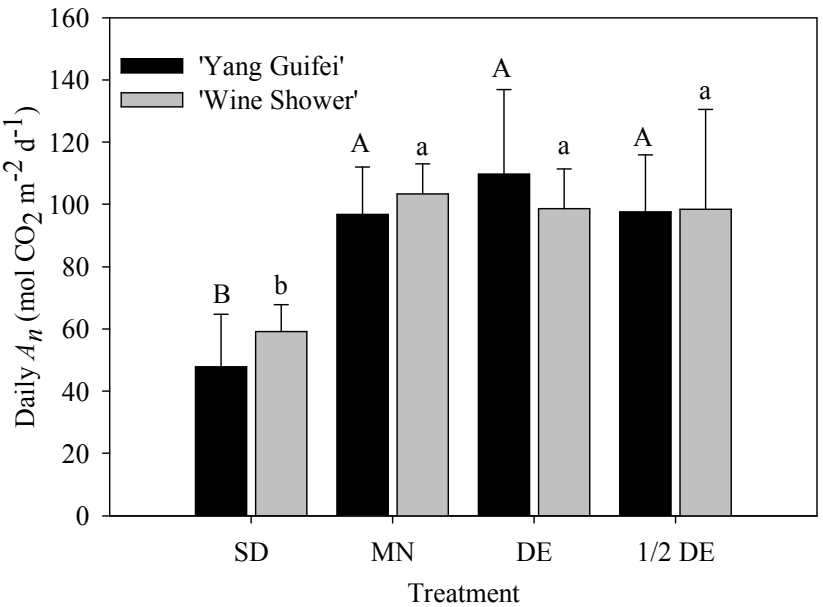

Fig. 7. Daily A_n of *Cymbidium* 'Yang Guifei' and 'Wine Shower' by different supplemental lighting timing in a day of non-supplemental lighting (SD), supplemental lighting at middle of night (MN), day extension (DE), and DE which was divided into two sections (1/2DE). Measurements were taken after 14 weeks of treatment. Vertical bars represents means and ± S.E. (n=3). Different letters above each bar indicate a significant difference at $p < 0.05$.

Duration and Intensity of Supplemental Lighting during Nighttime (Experiment 2)

Vegetative growth. In general, an increase in NSL duration and light intensity accelerated growth of *Cymbidium* 'Yang Guifei' and 'Wine Shower'. Particularly, pseudobulb diameter, number of leaves, and leaf width were higher by increasing NSL duration and light intensity, while leaf length had no significant difference among the treatments (Tables 3, 4 and Fig. 8). Leaf width was significantly ($p < 0.001$) affected by NSL light intensity. This result indicated that NSL duration and light intensity independently affects *Cymbidium* vegetative growth. However, since NSL duration and light intensity affect NSL light integral, it is expected that growth was significantly depends on NSL light integral.

In case of pseudobulb diameter, it was accelerated significantly ($p < 0.001$) as NSL duration and light intensity increased in both cultivars (Tables 3, 4 and Fig 8). The biggest pseudobulb diameter was found under 16 h-NSL duration with 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (11.52 $mol \cdot m^{-2} \cdot d^{-1}$) by 19.96 and 18.75 mm, in 'Yang Guifei' and 'Wine Shower', respectively. In *Cymbidium*, pseudobulb is a key factor of determining the maturity (Thomas and Vince-Prue, 1997). Pseudobulb is a storage organ of photosynthates, which accumulates massive amount of carbohydrates during vegetative development (Ng and Hew, 2000). Storage carbohydrates of pseudobulb is derived mainly from the import of currently assimilated carbon from leaves (Yong and Hew, 1995). Thus, leaves are the main sources of currently assimilated carbon and thus pseudobulbs represent an important supplementary source of carbohydrates that is utilized to meet the increased demand for carbon during inflorescence and new shoot development. Kim et al. (2011)

reported that *Cymbidium* had a minimum pseudobulb diameter requirement for inflorescence initiation which varied among different cultivars, for example, 4.4 cm for *Cymbidium* 'Yokihi' and 5.2 cm for 'Red Fire'. Ichihashi (1997), Lopez and Runkle (2006), and Blanchard and Runkle, (2008) also suggested that bulb forming orchids such as in *Dendrobium*, *Miltoniopsis, Odontioda*, the maturity of pseudobulb is size dependent and the size of the bulb is the most important for flower initiation. In this study, pseudobulb diameter increased by 33 and 43% bigger, correlated with an R^2 of 0.94 and 0.93 ($p < 0.001$) in 'Yang Guifei' and 'Wine Shower', respectively, under the highest NSL light integral. Thus, we could expect earlier initiation of inflorescence by reducing vegetative growth period and higher flower quality as discussed before in Kim et al. (2011).

Number of leaves and leaf width increased significantly as NSL duration and light intensity increased while leaf length was not influenced by NSL treatment in both cultivars (Tables 3, 4 Fig. 8). Leaf was the widest under the 16 h-NSL duration with 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ by 1.7cm in both cultivars (Tables 3 and 4). Within the same NSL light integrals (1.44, 2.88, and 5.76 $mol \cdot m^{-2} \cdot d^{-1}$), higher light intensity resulted in wider leaves compared with the lower light intensity. The increased number of leaves and leaf width ultimately increases the total leaf area of plants to photosynthesize. This makes it possible to absorb more light and thus accelerate the biomass (Konow and Wang, 2001; Park and Runkle, 2016). These results were also suggested in *Cyclamen* (Oh et al., 2009), impatiens and petunia (Lopez and Runkle, 2008). For example, *Cyclamen* has increased growth and hastened flowering as number of leaves increased (Oh et al., 2009).

Shoot and root dry weight increased at a quadric rate in both cultivars (Fig. 9). The highest shoot and root dry weight were found under 11.52 $mol \cdot m^{-2} \cdot d^{-1}$ treatment, 2.8 and 3.5 g in 'Yang Guifei' and 2.5 and 2.4 g in 'Wine Shower', respectively. Faust et al. (2005) also demonstrated that increasing DLI increased dry weight in several floriculture crops. Similar to those results, many of researches have reported the promotion of growth with higher light integral in *Eustoma* (Islam et al., 2005), wax begonia (Nemali and van Iersel, 2004), and petunia (Lopez and Runkle, 2008). For example, not in orchids, root and shoot biomass of petunia 'Tiny Tunia Violet Ice' were increased by 737% and 106%, respectively, after 16 days of propagation when plants were provided with a DLI of 1.2 to 7.5 $mol \cdot m^{-2} \cdot d^{-1}$ (Lopez and Runkle, 2008).

Table 3. Effect of nighttime supplemental lighting (NSL) duration and light intensity on pseudobulb diameter, number of leaves, leaf length, and leaf width in *Cymbidium* 'Yang Guifei' after 4 months of treatment

NSL duration	Light intensity ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	Pseudobulb diameter (mm)	No. of leaves	Leaf length (cm)	Leaf width (cm)
Non[z]	–	14.99gh[y]	12.3d	19.9	1.5b-f
2 h	10	14.80h	13.3bcd	20.5	1.4ehg
	100	15.48gh	13.2bcd	21.0	1.5b-e
	200	15.88fg	13.5a-d	20.0	1.5b-f
4 h	10	15.42gh	12.7cd	20.9	1.3g
	100	16.63ef	14.5ab	19.3	1.5b-e
	200	17.71bcd	14.5ab	20.7	1.5b-e
6 h	10	15.73gh	13.3bcd	20.6	1.5b-e
	100	16.97de	14.0abc	20.9	1.6bcd
	200	17.32cde	13.7ab	20.7	1.6abc
8 h	10	15.61gh	13.3bcd	20.3	1.4c-g
	100	16.84de	13.8abc	20.0	1.4c-g
	200	18.18bc	14.3ab	19.5	1.6ab
16 h	10	15.46gh	13.3bcd	20.5	1.3gf
	100	18.32b	14.0abc	20.6	1.4d-g
	200	19.96a	14.8a	20.0	1.7a
Significance					
NSL duration (D)		***	*	NS	NS
Light intensity (I)		***	***	NS	***
NSL light integral		***	**	NS	***
D × I		NS	NS	NS	**

[z]Plants were grown under different NSL durations of none, 2, 4, 6, 8, and 16 h and different light intensities of 10, 100, and 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$.
[y]Mean separation within columns by Duncan's multiple arrange test at $p < 0.05$.
NS, *, **, ***Non-significant, significant at $p < 0.05$, 0.01, or 0.001, respectively.

Table 4. Effect of nighttime supplemental lighting (NSL) duration and light intensity on pseudobulb diameter, number of leaves, leaf length, and leaf width in *Cymbidium* 'Wine Shower' after 4 months of treatment

NSL duration	Light intensity ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	Pseudobulb diameter (mm)	No. of leaves	Leaf length (cm)	Leaf width (cm)
Non[z]	–	13.11 gh[y]	11.5 c	20.1	1.4 def
2 h	10	12.97 h	12.2 abc	20.4	1.3 gf
	100	13.99 efg	12.2 abc	19.8	1.4 def
	200	14.96 de	12.7 abc	20.1	1.5 bcd
4 h	10	13.88 f-h	12.8 abc	20.0	1.3 gf
	100	14.64 d-f	12.8 abc	19.0	1.5 bcd
	200	15.51 cd	13.2 ab	20.1	1.6 abc
6 h	10	13.73 fgh	12.0 bc	19.6	1.2 g
	100	14.92 de	13.2 ab	19.5	1.4 def
	200	16.61 b	13.3 ab	18.6	1.6 ab
8 h	10	14.13 ef	12.3 abc	20.2	1.3 efg
	100	16.08 bc	13.5 a	20.0	1.5 bcd
	200	18.09 a	13.3 ab	19.4	1.6 ab
16 h	10	14.14 ef	12.8 abc	19.8	1.4 efg
	100	16.35 bc	13.2 ab	19.6	1.5 cde
	200	18.75 a	13.2 ab	18.9	1.7 a
Significance					
NSL duration (D)		***	**	NS	NS
Light intensity (I)		***	***	NS	***
NSL light integral		***	*	NS	***
D × I		NS	NS	NS	NS

[z]Plants were grown under different NSL durations of none, 2, 4, 6, 8, and 16 h and different light intensities of 10, 100, and 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

[y]Mean separation within columns by Duncan's multiple arrange test at $p < 0.05$.

[NS, *, **, ***]Non-significant, significant at $p < 0.05$, 0.01, or 0.001, respectively.

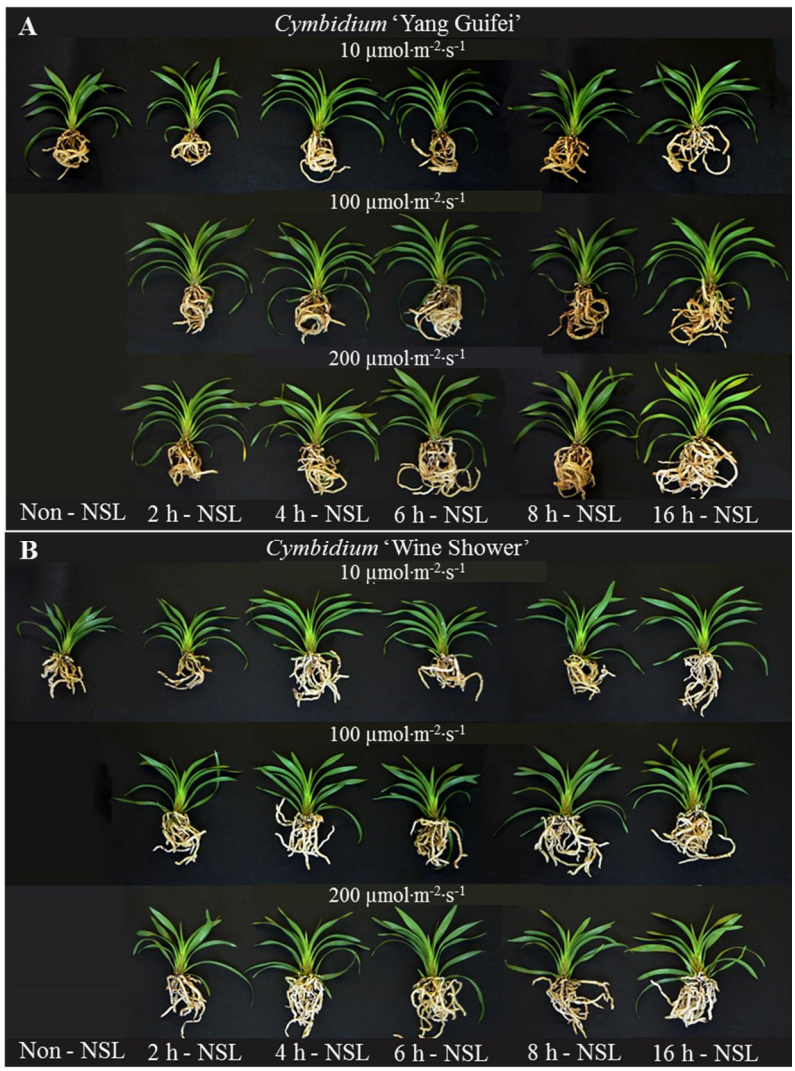

Fig. 8. Effect of nighttime supplemental lighting (NSL) on biomass characteristics of *Cymbidium* 'Yang Guifei' (A) and 'Wine Shower' (B) after 4 months of treatment. Plants were grown under different NSL durations of none, 2, 4, 6, 8, and 16 h and different light intensities of 10, 100, and 200 µmol·m^{-2}·s^{-1}.

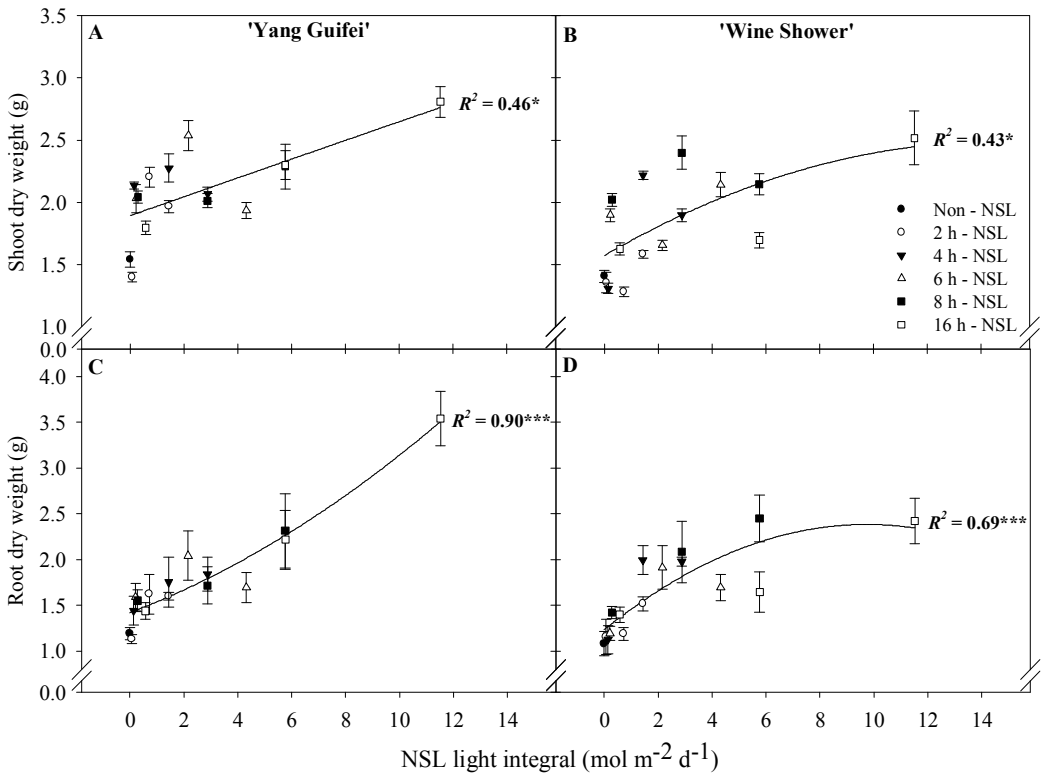

Fig. 9. Relationship between nighttime supplemental lighting (NSL) light integral and shoot (A, B) and root (C, D) dry weight. Shoot dry weight included pseudobulb and leaves of *Cymbidium* 'Yang Guifei' (A, C) and 'Wine Shower' (B, D). Plants were grown under different NSL durations of none, 2, 4, 6, 8, and 16 h and different light intensities of 10, 100, and 200 μmol·m^{-2}·s^{-1}. Vertical bars represent means and ± S.E. (n=4). *,***Significant at $p < 0.05$ or 0.001, respectively.

Chlorophyll contents. In *Cymbidium* 'Yang Guifei', chlorophyll contents significantly ($p < 0.001$) decreased with increasing NSL light integral (Fig. 10). In 'Wine Shower', however, there were no significant differences in chlorophyll contents among the NSL treatments. Nemali and van Iresel, (2004) and Torres and Lopez (2011) also reported that decrease of chlorophyll contents was observed when plants were exposed to over 20 $mol \cdot m^{-2} \cdot d^{-1}$. In this study, the average natural DLI was 7.16 $mol \cdot m^{-2} \cdot d^{-1}$, and the highest NSL light integral under which the plants showed the decrease of chlorophyll contents was 18.16 $mol \cdot m^{-2} \cdot d^{-1}$. In addition, the decrease of chlorophyll contents was observed in *Cymbidium* (Kim et al., 2015), eggplant (Murage et al., 1997), and tomato (Matsuda et al., 2014) under extended daylength. However, when plants were moved to natural daylength, chlorophyll contents showed recovery after 1 month of exposure to natural daylength in 'Yang Guifei' (Fig. 10). This result was corresponded with the result of Koo (2012). He reported that insertion of dark period after extended lighting cycle or several days after continuous lighting could avoid chlorosis and increased growth. Several studies have been conducted to prevent chlorosis and increase plant quality by additional nutrient supply (An et al., 2012; Kim et al., 2012) and by diurnal temperature change during continuous lighting in tomato (Matsuda et al., 2014; Haque et al., 2015).

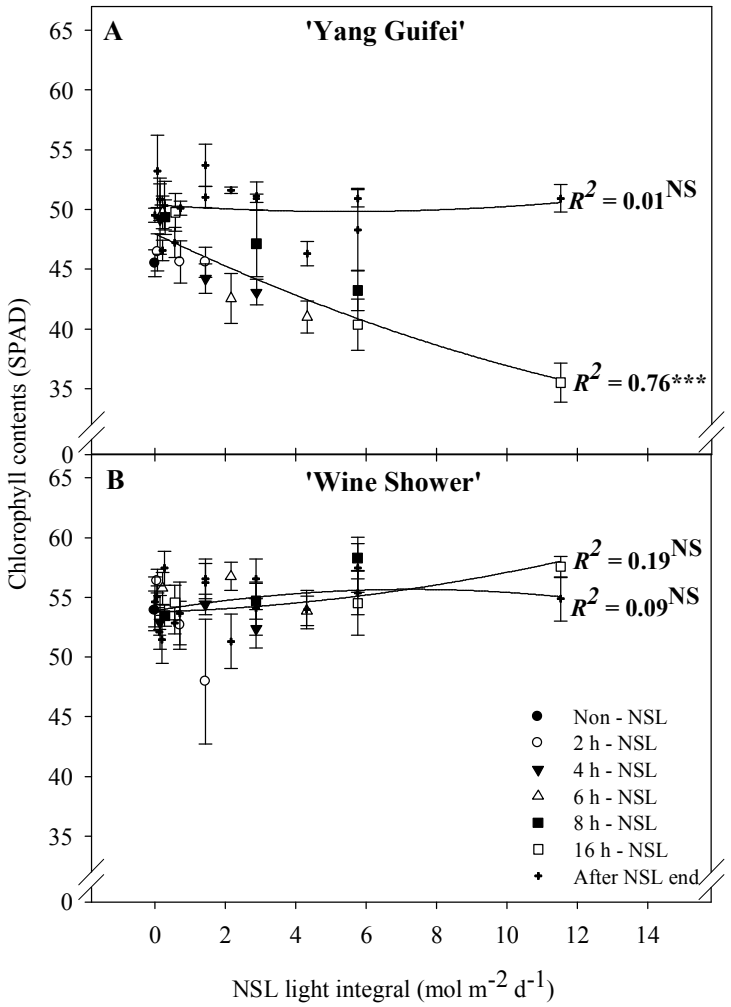

Fig. 10. Relationship between nighttime supplemental lighting (NSL) light integral and chlorophyll contents with SPAD reading of *Cymbidium* 'Yang Guifei' (A) and 'Wine Shower' (B). Plants were grown under different NSL durations of none, 2, 4, 6, 8, and 16 h and different light intensities of 10, 100, and 200 μmol·m^{-2}·s^{-1}. Vertical bars represent means and ± S.E. (n=6). $^{NS, ***}$Non-significant or significant at $p < 0.001$, respectively.

Photosynthetic assimilation rate. A_n of *Cymbidium* 'Yang Guifei' and 'Wine Shower' were monitored for 24 h after 2 months of growth under NSL treatments (Figs. 11 and 12). Generally, NSL induced additional photosynthesis during nighttime and enhanced A_n by increasing NSL duration and light intensity in both cultivars.

The maximum A_n at nighttime during NSL treatment occurred according to NSL light intensity. A_n was the highest under 200 μmol·m^{-2}·s^{-1} treatments followed by 100 and 10 μmol·m^{-2}·s^{-1} treatments (Figs. 11 and 12). Plants under 200 μmol·m^{-2}·s^{-1} treatments had more enhanced A_n during nighttime compared daytime due to elevated CO_2 concentration from 400 to 800 μmol·mol^{-1}. Controlling light intensity and CO_2 concentration enhances photosynthesis of *Cymbidium* (Kim et al., 2013b). Nemali and van Iersel (2004) reported that increasing light integral increased by light intensity promoted A_n, which could contribute to the growth promotion. Oh et al. (2009) also reported that the day extension with 200 μmol·m^{-2}·s^{-1} light intensity achieved the sufficient growth of *Cyclamen* by significantly enhancing A_n. A_n of 10 μmol·m^{-2}·s^{-1} treatments were higher than that of Non-NSL treatment, but A_n under 10 μmol·m^{-2}·s^{-1} treatments were observed below 0 μmol CO_2·m^{-2}·s^{-1} level (Figs. 11 and 12). Light compensation points of *Cymbidium* cultivars used in this study, were below the 10 μmol·m^{-2}·s^{-1} (Fig. 13). It is expected that the amount of respiration was larger than that of photosynthesis. In many studies small increase of NSL light intensity, such as 3–5 μmol·m^{-2}·s^{-1}, has often been ignored because of negligible effect on subsequent growth in *petunia* (Adams et al., 2008), *chrysanthemum* (Markvart et al., 2009; Kjaer and Ottosen, 2011), *Dianthus chinensis, Zinnia elegans,* and *Pelargonium* ×*hortorum* (Park et al., 2013).

Prolonged A_n periods at nighttime were observed due to longer NSL durations, but in plants which exposed to the 16-NSL (continuous lighting) with 100 and 200 μmol·m^{-2}·s^{-1}, a marked decrease in A_n were observed in both daytime and nighttime, especially in *Cymbidium* 'Yang Guifei' (Figs. 11F and 12F). Light saturation point for two *Cymbidium* cultivars used in this study, were around 200 μmol·m^{-2}·s^{-1} (Fig. 13). Plants under 16 h-NSL duration with 100 and 200 μmol·m^{-2}·s^{-1} (ranging from 5.76 to 11.52 mol·m^{-2}·d^{-1}), might have occurred a photo-oxidative damage, forming reactive oxygen species (del Rĭo, 2015; Gill and Tuteja, 2010) such as superoxide, hydroxyl radical, and hydrogen peroxide. These ROS can cause oxidative cell injury, resulting in the decrease of chlorophyll contents also seen in this study (Fig. 10) and down-regulation of photosynthesis follows. In addition to high light intensity, long duration of artificial light can be harmful. The response of down-regulation of photosynthesis (Sysoeva et al., 2010; Velez-Ramirez et al., 2011) was exhibited in tomato when they were exposed to excessive long photoperiod; continuous lighting, and decreased of chlorophyll contents (Hilman, 1956; Matsuda et al., 2014). Accumulation of carbohydrate by higher photosynthesis under abnormal lighting conditions is an important factor in inducing chlorosis under continuous lighting (Demers et al., 1998; van Gestel et al., 2005). Recently, Velez-Ramirez et al. (2017) found that carbohydrates play an important role in continuous light-induce injury. A strong negative correlation between sucrose and starch content with severity of continuous light-induce damage quantified as the maximum quantum efficiency of PSII in abnormal light/dark cycle. Injured tomato by down regulation of photosynthesis shows cytokinin-regulated senescence and light modulated retrograde signaling. Despite the depression of A_n under 16 h-NSL, daily A_n significantly

($p < 0.001$) increased with increasing NSL light integral in both cultivars (Fig. 14). As plants received higher NSL light integral and photosynthesized more by 262% and 397% in 'Yang Guifei' and 'Wine Shower', respectively, as NSL light integral increased from 0 to 11.52 $mol \cdot m^{-2} \cdot d^{-1}$. This result was also reported in wax begonia where plants under high DLI had increased whole plant photosynthesis and carbon use efficiency (Nemali and van Iersel, 2004).

Pseudobulb diameter and daily A_n were correlated with an r^2 of 0.75 and 0.87 in 'Yang Guifei' and 'Wine Shower', respectively at $p < 0.001$ (Fig. 15). This result indicates that promotion of pseudobulb diameter was positively related to accumulation of photosynthetic products as discussed before (Yong and Hew, 1995; Ng and Hew, 2000; Kim et al., 2015).

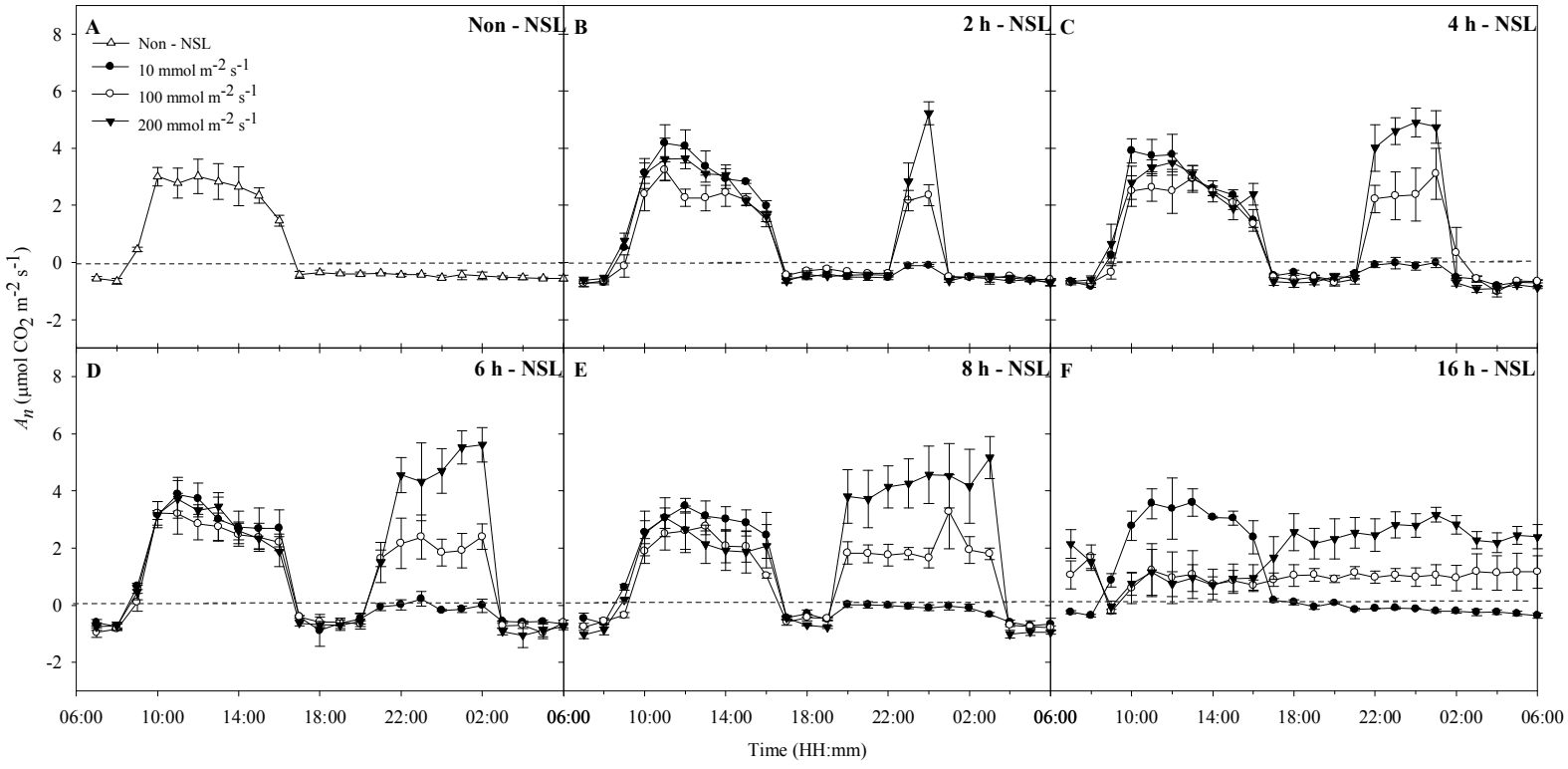

Fig. 11. Net photosynthetic assimilation rate (A_n) of *Cymbidium* 'Yang Guifei' as influenced by different duration of nighttime supplemental lighting (NSL) for none (A), 2 (B), 4 (C), 6 (D), 8 (E), and 16 hours (F) at different light intensities (10, 100, and 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$). Measurements were taken after 8 weeks of treatment. Vertical bars represent means and ± S.E. (n=3).

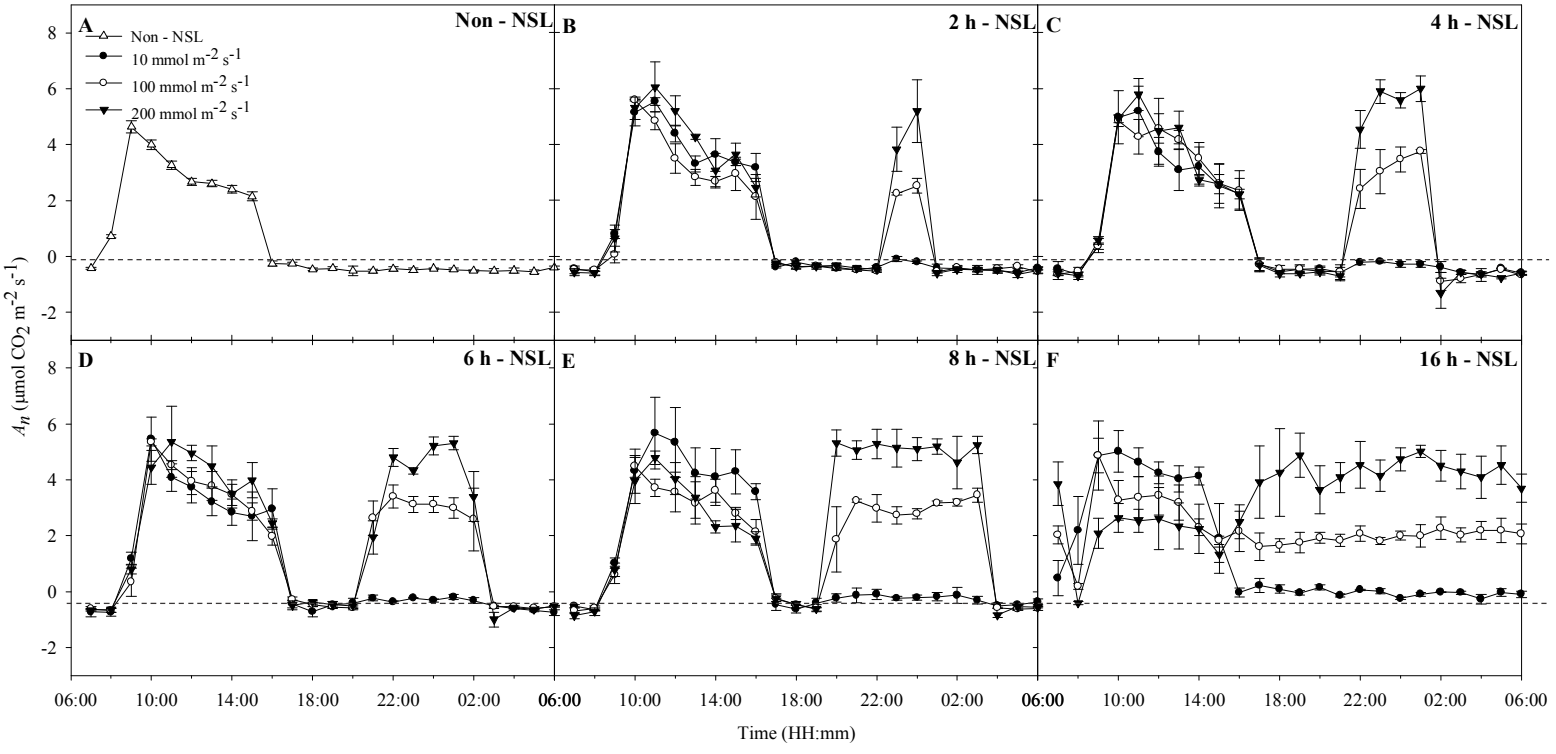

Fig. 12. Net photosynthetic assimilation rate (A_n) of *Cymbidium* 'Wine Shower' as influenced by different duration of nighttime supplemental lighting (NSL) for none (A), 2 (B), 4 (C), 6 (D), 8 (E), and 16 hours (F) at different light intensities (10, 100, and 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$). Measurements were taken after 8 weeks of treatment. Vertical bars represent means and ± S.E. (n=3).

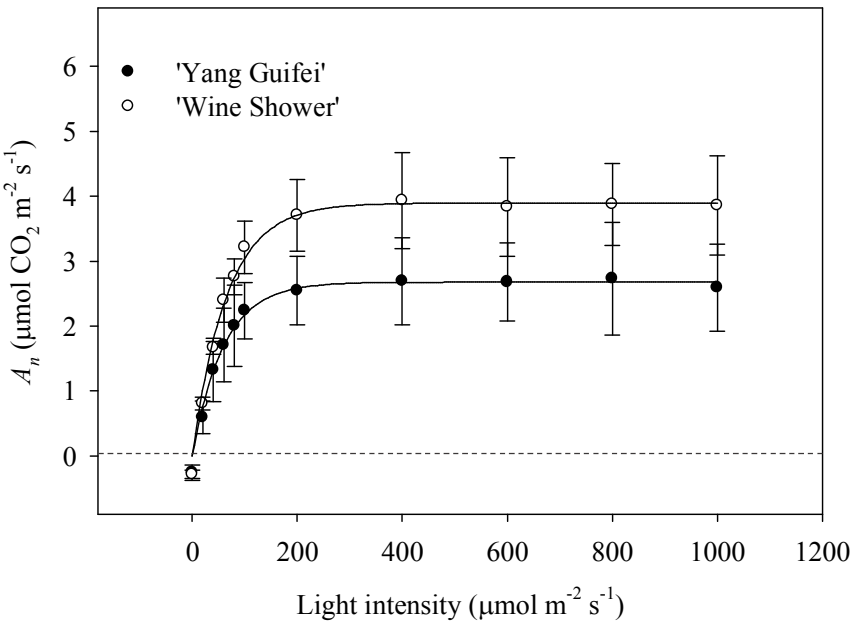

Fig. 13. Net photosynthetic assimilation rate (A_n) in response to incident light intensity of *Cymbidium* 'Yang Guifei' and 'Wine Shower' when CO_2 concentration was 400 μmol·mol^{-1}. Measurements were taken after 8 weeks of plants in Non-NSL treatment. Vertical bars represent means and ± S.E. (n=3).

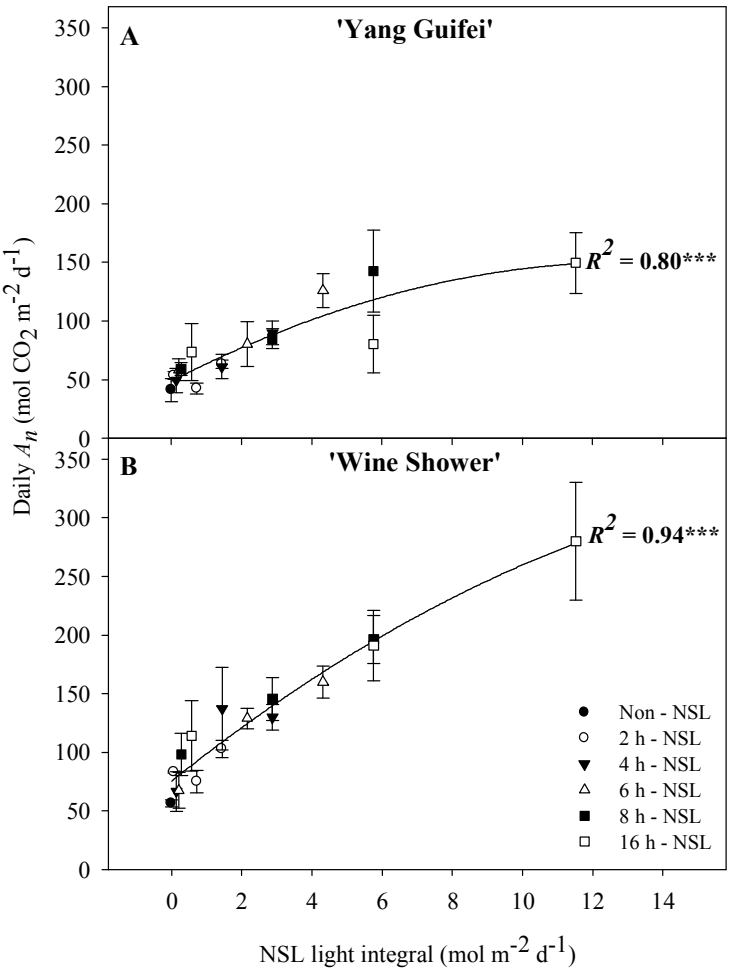

Fig. 14. Relationship between nighttime supplemental lighting (NSL) light integral and daily A_n of *Cymbidium* 'Yang Guifei' (A) and 'Wine Shower' (B). Measurements were taken after 8 weeks of treatment. Plants were grown under different NSL durations of none, 2, 4, 6, 8, and 16 h and different light intensities of 10, 100, and 200 µmol·m^{-2}·s^{-1}. Vertical bars represent means and ± S.E. (n=3). ***Significant at $p <$ 0.001.

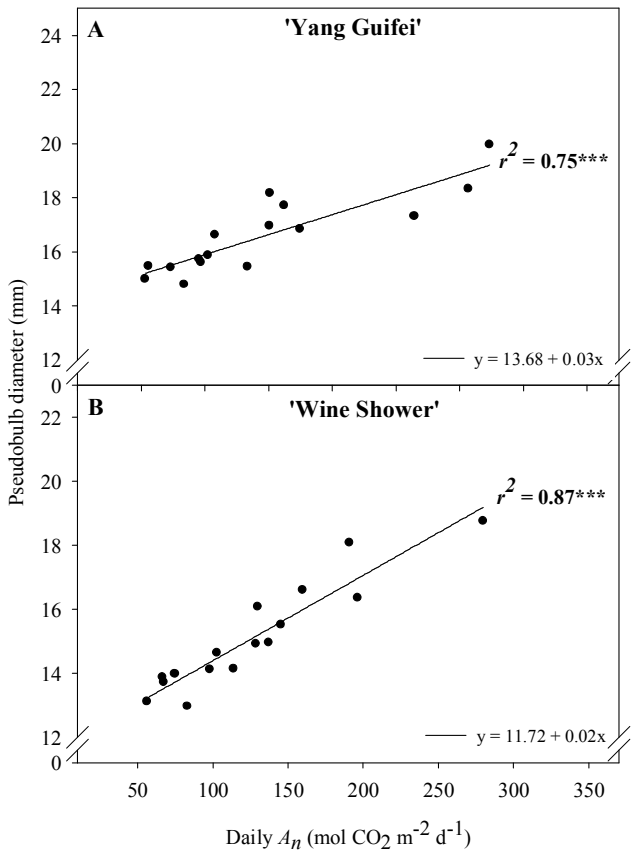

Fig. 15. Relationship between daily A_n and pseudobulb diameter of *Cymbidium* 'Yang Guifei' (A) and 'Wine Shower' (B). Plants were grown under different NSL durations of none, 2, 4, 6, 8, and 16 h and different light intensities of 10, 100, and 200 μmol·m^{-2}·s^{-1}. ***Significant at $p < 0.001$.

In conclusion, *Cymbidium* 'Yang Guifei' and 'Wine Shower' were grown under different supplemental lighting timings and different NSL duration and light intensity to promote vegetative growth. The findings in the present study suggest that increasing supplemental lighting duration and light intensity with higher light integral during nighttime, promotes vegetative growth and enhances photosynthesis. Commercially viable plants require sufficient vegetative growth to support high quality flowering and it should be rapid in production. Extended production period increases cost, including labor cost and maintenance cost such as heating and cooling expenses. Thus, the NSL is useful to increase DLI and promote production of *Cymbidium,* especially during winter season, when DLI is less than 10 $mol \cdot m^{-1} \cdot d^{-1}$. Since there were no differences in growth and photosynthesis between NSL and DE, efficiency of supplemental lighting is independent from what time of the day it is used. Thus, supplemental lighting can be controlled in accordance with hourly electricity prices for economic advantage during the dark and low light periods in winter.

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ABSTRACT IN KOREAN

본 연구는 겨울철 심비디움 재배 시 영양생장과 광합성 증진을 위한 하루 중 보광 처리 시간, 보광 주기와 보광 광도를 알아보기 위해 수행하였다. 기존 재배 방법보다 영양생장을 촉진하여 재배 작기를 단축하고 에너지 효율을 극대화하는 방법을 개발하고자 한다. 첫 번째 실험에서는 하루 중 보광 처리 시간에 따른 영양생장과 광합성을 알아보기 위한 실험으로 9 개월 된 *Cymbidium* 'Yang Guifei' 와 'Wine Shower'을 사용하였으며, 보광을 하지 않은 무처리(8/16 h, SD)와 4 시간의 보광 처리 시간에 따라 22:00–02:00 $_{HR}$(밤 중간, MN), 두 가지 방식의 일장 연장인 17:00–21:00 $_{HR}$(일장 연장, DE), 그리고 07:00–09:00 와 17:00–19:00 $_{HR}$(두 개로 나뉜 일장 연장, 1/2DE)로 처리하였다. 두 번째 실험으로 보광 주기와 광도를 달리하여, 야간 보광 시 적산광량에 따른 영양생장과 광합성 반응을 알아보고자 2 개월 된 같은 품종으로 실험을 진행하였다. 야간 보광 시 광도는 10, 100, 그리고 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ 였으며, 광주기는 2, 4, 6, 8, 그리고 16 시간(24 시간 동안 광에 노출)으로 총 16 개 처리 하였다. 두 실험에서 모두 적색광 LEDs 를 사용하였으며, 보광 시 이산화탄소를 800 $\mu mol \cdot mol^{-1}$ 시비하였다. 전반적으로 두 품종 모두에서 보광 처리 하에서, 하루 중 보광 처리 시간과 관계없이, 영양생장과 광합성이 증가함을 확인하였다. 보광 처리들은 일적산광량(DLI)이 동일했으므로, DLI 가 보다 생장과 광합성에 영향을 미칠 것으로 추측되었다. 두 번째 실험 결과, 야간 보광 시 광 주기와 광도의 증가함에 따라 두 품종에서 모두 위구경의 직경, 엽수, 엽폭이 모두 증가하였으며, 특히 'Yang Guifei' 품종의 경우에는 야간 보광 시

적산광량이 증가함에 따라 엽록소 함량이 유의하게 감소하는 양상을 보였는데, 4 개월간의 겨울철 보광을 마치고 자연 일장으로 돌아왔을 때, 엽록소 함량이 다시 증가하였다. 16 시간의 보광 주기에서 순광합성률이 다소 낮은 양상이 있었으나, 하루 동안의 광합성량은 야간 보광 시 적산광량이 증가함에 따라 증가하는 양상을 보였다. 결론적으로 야간 보광 시 적산광량이 증가함에 따라 광합성이 증가하였고, 광합성 산물 축적으로 인해 위구경이 증가됨을 확인 할 수 있었다. 이런 결과를 통해 심비디움의 영양생장을 증진하기 위해 겨울철 야간 보광을 함으로써 재배 기간을 단축하고 고품질의 심비디움을 생산할 수 있을 것으로 판단된다.