

THE PHOTOSYNTHETIC CHARACTERISTICS OF WILD *CYMBIDIUM FABERI* ROLFE IN THE QINLING MOUNTAINS, CHINA

JUNYANG SONG AND NING ZHANG^{1*}

College of Landscape Architecture and Arts, Northwest A & F University,
Yangling, Shaanxi, 712100, China

Keywords: Photosynthetic characteristics, *Cymbidium faberi*, Qinling mountains, Light compensation point, Light saturation point

Abstract

Seven species of orchids in the genus *Cymbidium* (Orchidaceae) have been cross-bred to create more than 220 hybrids that serve as popular cultivated ornamentals. The present study examined the daily variation in the patterns of the net photosynthetic rate and the photosynthetic response of wild *Cymbidium faberi* in the Qinling Mountains in northwestern China. The photosynthetic characteristics of this species were studied under natural conditions with a portable photosynthesis system. Double peaks were observed in the net photosynthetic rate with one around 09:00 and another around 17:00 in spring, as well as one around 11:00 and another around 15:00 in winter. Midday depression of photosynthesis was observed in wild *C. faberi* plants around 13:00 in both spring and winter. The net photosynthetic rate was strongly positively correlated with both stomatal conductance ($r = 0.913$) and the transpiration rate ($r = 0.659$), and weakly negatively correlated with the intercellular carbon dioxide concentration ($r = -0.094$). The results show that the light compensation point (LCP) and the light saturation point (LSP) of wild *C. faberi* were 25.78 and 384 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, respectively. The result provides a reference for cultivation management especially in the light management of *Cymbidium*.

Cymbidium faberi (Orchidaceae) is one of several traditional and famous orchid flowers in China. The Chinese have cultivated orchids for more than 2500 years. Most of the scientists currently recognize seven *Cymbidium* species in China: *C. sinense* (Jackson ex Andr.) Willd., *C. ensifolium* (L.) Sw., *C. goeriugii* (Rchb. f.) Rchb. f., *C. faberi* Rolfe., *C. kanrau* Makino., *C. lianpan* Tang & F.T. Wang ex Y.S. Wu, *C. longibracteatum* W.S. Wu & S.C. Chen (Zeng *et al.* 2013). To date, the British Royal Horticultural Society has registered 227 hybrids derived from Chinese orchids. Chinese orchids have been used as parents in the breeding of *C. faberi* because it is easy to grow, exhibits various flower colors and types, and gives off a sweet fragrance.

Wild populations of *C. faberi* are mainly distributed in the southern mountainous area of China. The Qinling Mountains support the most northern population of wild *Cymbidium* species in China, where light serves as one of the most important factors affecting its natural distribution, growth, and development. The Qinling Mountains, located at 32°40' - 34°35'N, 105°30' - 110°05'E, run through the central region of China and lie sandwiched between the Wei and Han rivers. This region also forms a natural and geographical boundary between northern and southern China. The mountains of the Tibetan Plateau rise to the west, while the Funiu and Dabie mountains lie to the east of the Qinling. The temperate climate north of the Qinling Mountains and the subtropical climate to the south result in a rich variety of natural plant resources in this region.

In recent years, many workers have been interested in the photosynthetic characteristics of various plants in the Orchidaceae (Li *et al.* 2005, Liu *et al.* 2014, Zhang *et al.* 2014), whereas few studies have addressed the growth of *C. faberi* (Li *et al.* 2005), specially for those plants growing

*Author for correspondence: <znaw@nwsuaf.edu.cn>. ¹College of Water Resources and Architectural Engineering, Northwest A&F University, Yangling 712100, China.

in natural environments. The goal of the present study was to explore the daily photosynthetic patterns of *C. faberi* plants under natural conditions in both winter and spring. Wild *C. faberi* plants in the Qinling Mountains were examined to determine the net photosynthetic rate, photosynthetic response and other physiological parameters. These included stomatal conductance, transpiration rate, intercellular carbon dioxide (CO₂) concentration, the light saturation point (LSP) and the light compensation point (LCP). The data presented in this study provide a foundation for cultivation management (Light management) of *Cymbidium* orchid and the conservation of wild *C. faberi* in the Qinling Mountains.

The experiment was conducted at Qianjiaping village, Shangnan County, Shaanxi Province, China, which is located in the eastern part of the Qinling Mountains at 33°20'42.7"N, 110°41'0.14"E 816 m a. s. l. where typical populations of wild *C. faberi* occur. The plants chosen in the present study grew on a 43° southwest facing slope. *Quercus variabilis*, the dominant tree species in this area, reaches heights of about 25 m and has a canopy density of 0.4 - 0.5. Few shrubs grew under these trees. In this region, the mean annual, maximum, and minimum temperatures were 13.9, 26.8°C, respectively in July with an extreme high of 41.3 and 1.5°C in January with an extreme low of -13.1°C, respectively. The average annual rainfall was 829.8 mm with an average of 137 rainy days each year. The annual average relative humidity was 68.5% with a mean of 1973.5 hrs of sunshine annually and a frostless period of 216 d; climatic data were collected between 1978 and 2008 (Zhang *et al.* 2010).

The net photosynthetic rate (P_n , $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$), effective photosynthetic radiation (PAR , $\mu\text{mol photons}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$), stomatal conductance (G_s , $\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$), transpiration rate (T_r , $\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) and intercellular CO₂ concentration (C_i , $\mu\text{mol}\cdot\text{mol}^{-1}$) were measured in an open-flow gas exchange system (LI-6400, Li-Cor Inc., Lincoln, NE, USA).

The daily net photosynthetic rate was measured using blooming wild *C. faberi* plants in the Qinling Mountains in April 2016. The seasonal net photosynthetic rates were measured in January 2016 (winter) and April (spring), 2016, respectively. Sunny days were selected for all measurements that were made using one healthy leaf from each of five randomly selected plants at the experiment site. The measuring time started at 08:00 and continued until 20:00 with hourly interval. Each measurement was repeated ten times with the mean to be used for statistical analysis.

The photosynthetic responses were measured between 09:00 - 11:00 on clear sunny days in April 2016 using the method of Gomes *et al.* (2006). The following criteria were employed: the CO₂ concentration in leaf chamber was 375 $\mu\text{mol}/\text{mol}$ with a leaf chamber temperature of 27°C and air relative humidity of 68%. First, measurement of the light saturation was carried out for 30 min; photosynthetic active radiation (PAR) was set up to descend at 600, 500, 400, 300, 200, 100, 80, 60, 40, 20, 10, 0 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ during the tests by using a 6400 - 02B LED light source that was designed also to capture data automatically. Each measurement of five samples was replicated ten times with means used for analysis. The net photosynthetic rate-photosynthetically active radiation (P_n - PAR) curve of the photosynthetic response was calculated following Thornley's non-rectangular hyperbola (Thornley 1998). The linear regression of the net photosynthetic rate to light intensity was calculated under 0 - 60 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ of photosynthetically active radiation. The slope of the linear equation was the initial quantum yield. The LCP (light compensation point) and LSP (light saturation point) of wild *C. faberi* were calculated based on the curve of the photosynthetic response.

Data processing and drawing were conducted using Microsoft Excel 2003. The linear regression and correlation analyses were carried out using SPSS v.17.0.

The net photosynthetic rate of wild *C. faberi* increased starting from 08:00 with an initial peak of 1.64 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at 09:00 and then decreased until 12:00 including a dramatic decrease between

11:00 and 12:00. Immediately after noon from 12:00 to 13:00, the net photosynthetic rate gradually decreased to its lowest point of $0.28 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at 13:00, i.e., midday depression or ‘noon break.’ After a short period of midday depression, the net photosynthetic rate gradually increased until peaking again at 17:00 at $0.69 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ followed by a decrease to $0.30 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (Fig. 1). In contrast, the effective photosynthetic radiation gradually increased from 08:00 to a maximum of $600.21 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at 12:00. After 12:00, it gradually decreased to $140.41 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at 18:00 (Fig. 1). When the effective photosynthetic radiation reached peaked at noon, the net photosynthetic rate decreased to its second lowest rate of $0.36 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (Fig. 1). The high light intensity may have caused the net photosynthetic rate to decrease around noon and forced a slowdown in plant photosynthesis during the “noon break.”

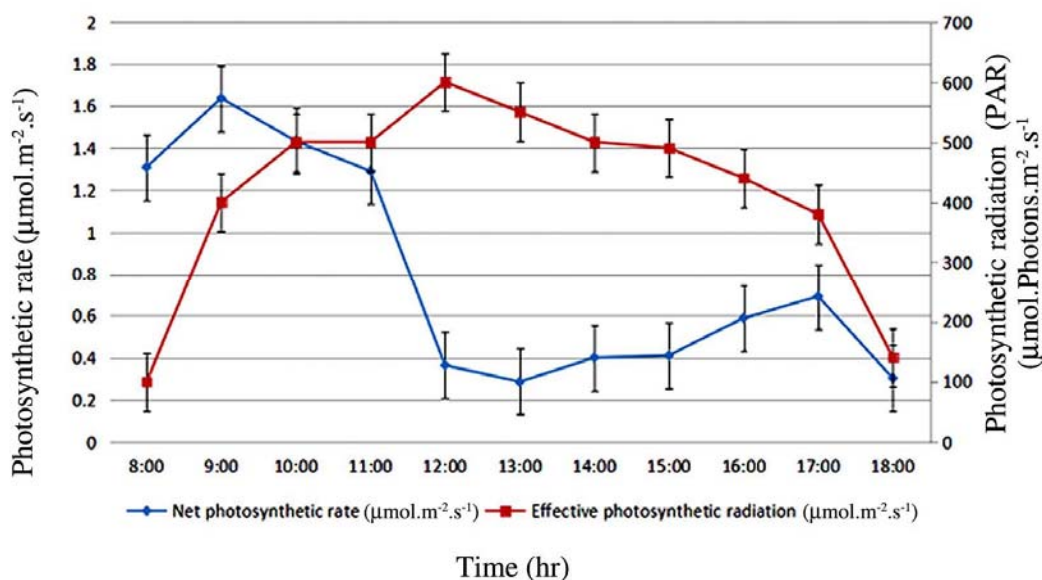


Fig. 1. The daily patterns of P_n and effective photosynthetic radiation in *Cymbidium faberi*

The daily changes of stomatal conductance of wild *C. faberi* followed the same pattern as did the net photosynthetic rate (Fig. 2). The first peak (maximum $0.0160 \text{ mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) in stomatal conductance occurred at 09:00 as did the peak in the net photosynthetic rate; however, the second peak ($0.0060 \text{ mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) occurred at 16:00, one hour earlier than that of the net photosynthetic rate. In addition, the lowest stomatal conductance ($0.0027 \text{ mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) was observed at 12:00, one hour earlier than that of the P_n (Fig. 2). The very similar daily change in the patterns of stomatal conductance and P_n showed that these two were significantly correlated ($r = 0.913$ at $p < 0.01$).

The daily changes in the transpiration rate of *C. faberi* also showed a double peak pattern with the highest peak of $0.23 \text{ mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at 9:00 and a second peak of $0.20 \text{ mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at 16:00 (Fig. 3), which followed the same pattern as that of the stomatal conductance. A significant correlation was observed between the net photosynthetic and transpiration rates ($p = 0.05$; $R = 0.659$). When compared with the P_n , the daily changes in the transpiration rate showed a relatively flat pattern.

The daily changes of the intercellular CO_2 concentration of *C. faberi* had a different pattern from that of the P_n (Fig. 4). The intercellular CO_2 concentration started at $278.2 \mu\text{mol}\cdot\text{mol}^{-1}$ at 08:00 and decreased to $156.5 \mu\text{mol}\cdot\text{mol}^{-1}$ at 11:00. Around noon, the intercellular CO_2 concentration peaked

at $315.1 \mu\text{mol}\cdot\text{mol}^{-1}$ and then fell dramatically to $171.8 \mu\text{mol}\cdot\text{mol}^{-1}$. After 13:00, the intercellular CO_2 concentration gradually decreased to the lowest value of $140.3 \mu\text{mol}\cdot\text{mol}^{-1}$ at 17:00. From 17:00, the intercellular CO_2 concentration began to increase and reached $238.2 \mu\text{mol}\cdot\text{mol}^{-1}$ at 18:00.

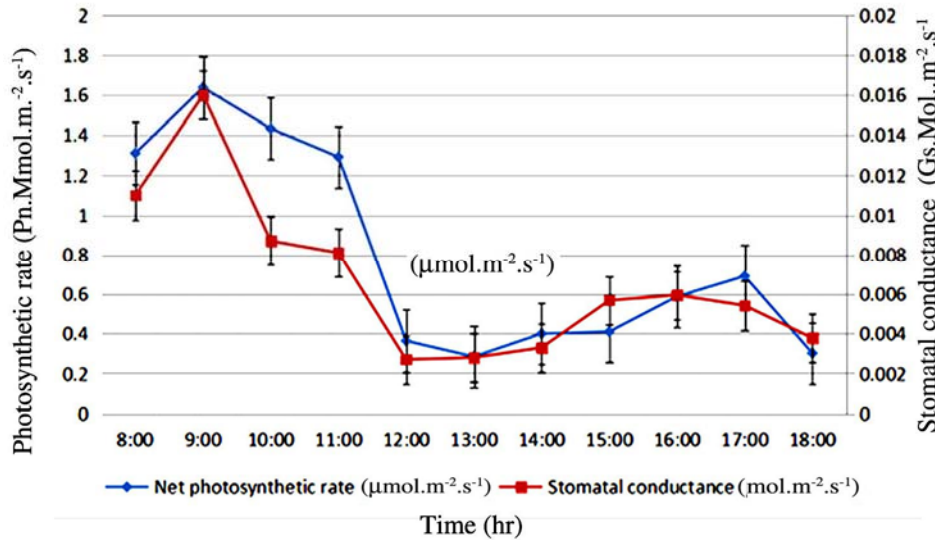


Fig. 2. The relationship between P_n and stomatal conductance in *Cymbidium faberi* during a typical day.

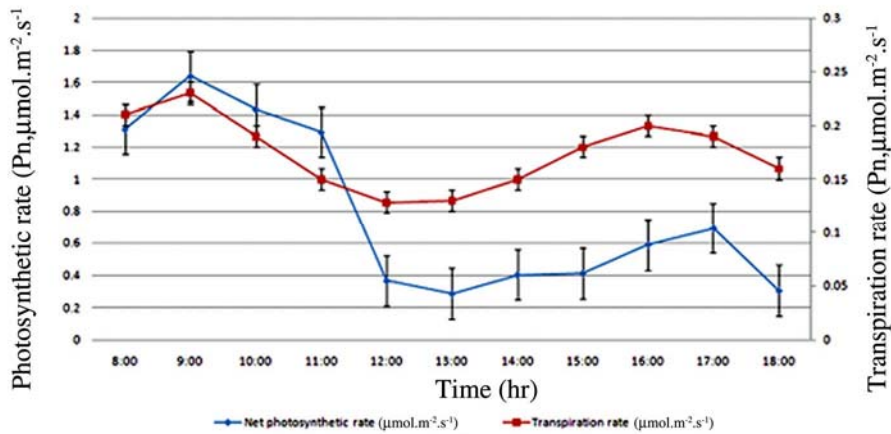


Fig. 3. The relationship between P_n and transpiration rate in *Cymbidium faberi* during a typical day.

The intercellular CO_2 concentration had an opposite pattern of change when compared with that of the P_n although this correlation was not significant ($R = -0.094$; Fig. 4). It decreased with an increase in the P_n and vice versa. Intercellular CO_2 is known to accumulate at night. Photosynthesis begins at sunrise, so the intercellular CO_2 concentration begins to decrease. As mentioned above, the midday depression of photosynthesis in wild *C. faberi* led to a decrease of the P_n between 12:00 to 13:00. Therefore, the decrease in the photosynthetic rate caused an increase in the intercellular CO_2 concentration.

Fig. 5 shows that the patterns of the P_n in spring and winter both exhibited double peaks. However, the peaks of the P_n occurred at different times when compared to those of winter to spring. For example, the highest peaks in winter and spring; that is, peaks of $0.82 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and $1.64 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ occurred at 11:00 in winter and 09:00 in spring, respectively. The second peak of the P_n occurred at 15:00 and 17:00 in winter and spring, respectively. Similarly, a midday depression of photosynthesis occurred at 13:00 in both spring and winter (Fig. 5). The average P_n of *C. faberi* in winter ($0.26 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) was smaller than that in spring ($0.79 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$). This occurred because plants received a smaller amount of effective photosynthetic radiation in winter than in spring (Fig. 6).

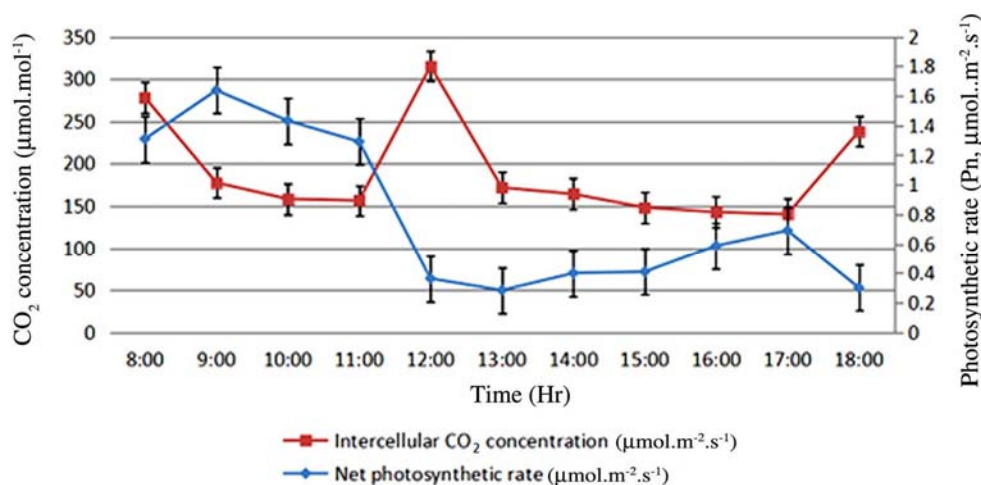


Fig. 4. The relationship between P_n and intercellular carbon dioxide concentration in *Cymbidium faberi* during a typical day.

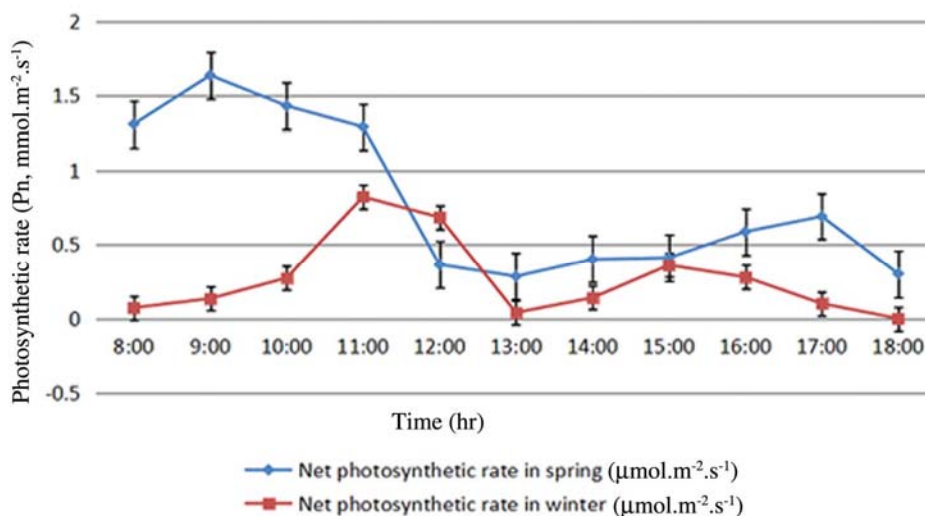


Fig. 5. Seasonal variation of P_n in *Cymbidium faberi* during a typical winter and spring day.

The effective photosynthetic radiation in winter and spring presented the same pattern, with an increase from 08:00 to a peak at 11 in winter and 12:00 in spring, and then it gradually decreased to the lowest value at 18:00 in both seasons (Fig. 6).

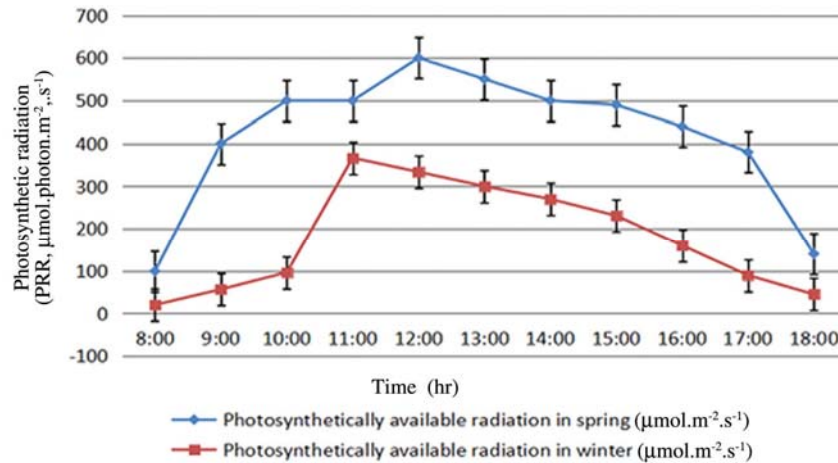


Fig. 6. Seasonal variation of effective photosynthetic radiation in *Cymbidium faberi* during a typical winter and spring day.

Fig. 7 shows that the changes in the photosynthetic response. the P_n -PAR curve demonstrating relationship of the P_n and effective photosynthetic radiation. P_n -PAR curves showed a parabolic shape (Fig. 7) When the effective photosynthetic radiation ranged between 0 and 60 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, the change of the P_n presented a linear increase. However, when the effective photosynthetic radiation was between 200 and 400 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, the P_n remained at a relatively high level with a maximum of 2.41 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at around 400 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. When the effective photosynthetic radiation was greater than 400 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, the P_n began to decrease, showing a light suppression phenomenon. This indicates that the range of light intensity used by wild *C. faberi* in the Qinling Mountains was relatively narrow.

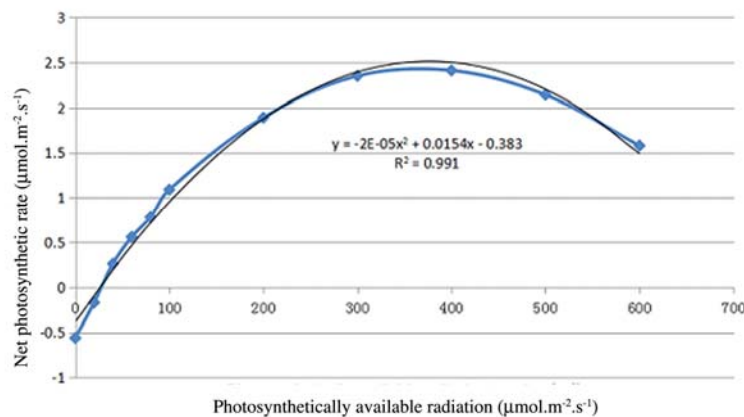


Fig. 7. Light responsive curve in *Cymbidium faberi* plotting photosynthetically available radiation against the P_n .

A quadratic equation for the photosynthetic response of *C. faberi* was obtained: $y = -0.00002x^2 + 0.01537x - 0.38298$ ($R^2 = 0.991$). Based on this equation, when the effective photosynthetic radiation was $25.78 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, the P_n was zero. Also, when the effective photosynthetic radiation was $384 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, the P_n peaked ($2.57 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$). After the effective photosynthetic radiation reached $384 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, the P_n decreased, even when the effective photosynthetic radiation increased. Therefore, the LCP and the LSP of wild *C. faberi* in the Qinling Mountains were $25.78 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and $384 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, respectively.

Photosynthesis is one of the important factors for plant adaptation, substance accumulation, and metabolism, as well as serves as the critical factor influencing plant growth, development, and productivity (Jin *et al.* 2011, Zhang *et al.* 2012). However, photosynthesis is influenced by both genotype and environment as well as their interaction (Yang *et al.* 2014). Multiple factors in the environment are known to interact and affect plant photosynthesis (Zhang and Xu 2000). In the present study, the daily pattern of change in the P_n of wild *C. faberi* in the Qinling Mountains presented double peaks, as described above with a period of midday depression occurring between them. This phenomenon might be closely related to plant physiological, biochemical, and environmental factors, and perhaps to other unknown factors. The midday depression in *C. faberi* might be caused by the closing of stomata in leaves at noon. In addition, the strong light intensity at noon results in the suppression of photosynthesis creating a short period of diurnal dormancy.

The factors that influence plant growth and their interactions vary at different stages of plant development (Zhang and Xu, 2000). Those environmental variables may cause changes in the strength of plant photosynthesis allowing plants to adapt to changes in the environment. The daily pattern and change in the P_n showed this rate was lower in winter than in spring in wild *C. faberi*. The peak P_n in spring occurred 2 hrs earlier than in winter, but the second high peak was delayed by 2 hrs in spring when compared with that in winter. These results agreed with similar results in *Carex leucochlora* (Yang *et al.* 2014). The seasonal changes in the P_n in winter and spring were mainly caused by seasonal differences in temperature and light intensity, suggesting that the P_n is significantly related to environmental conditions.

The analysis of the relationship between the P_n and other physiological factors suggests that the P_n had a strong positive correction with stomatal conductance and transpiration rate, and a weak negative correction with the concentration of intercellular CO_2 . Hou *et al.* (2011) and Zhang *et al.* (2012) found that the P_n of *Parispolyphylla* var. *yunnanensis* was positively correlated with stomatal conductance, while Li *et al.* (2012) found that these two were negatively correlated. Stomata provide a channel for the exchange of gases between the cells of plant leaves and the external environment. Stomatal conductance can serve as an indicator of the degree of stomatal opening on the surface of plant leaves. Stomatal conductance and the intercellular CO_2 concentration have significant effects on plant photosynthesis and transpiration. Previous research studies have indicated that stomatal and non-stomatal restrictions can lead to a decline in the photosynthetic rate; these restrictions are differentiated by the intercellular CO_2 concentration and its pattern of change (Zhang *et al.* 2006). The P_n of the wild *C. faberi* leaf decreased with a decrease in stomatal conductance, indicating that stomatal conductance is the one of the cause of this change. Stomatal conductance affects both the intercellular CO_2 concentration and the transpiration rate. Effective photosynthetic radiation and stomatal conductance, which are the main factors influencing the plant photosynthesis, combined to determine the photosynthetic rate of wild *C. faberi*,

The LCP and the LSP reflect the requirements of plants for light and light energy use. Based on the LSP and LCP values, plants with a low LCP and high LSP are adapted to a wide range of light strength, while plants with a relatively high LCP and low LSP require a narrow range of light strength (Cai *et al.* 2013). From this study it is revealed that the LCP and LSP of wild *C. faberi* in

Qinling Mountains were $25.78 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and $384 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, respectively, compared to the $500 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and $10 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ in cultivated *C. faberi* species (Li *et al.* 2005). The differences between the LCP and LSP are the result of long-term adapt to the environmental conditions under which the plants grew. Kim *et al.* (2015) investigated photosynthetic change in *Cymbidium* orchids grown under intensities of night interruption lighting and reported that photosynthetic photon flux of $120 \mu\text{mol m}^{-2} \text{s}^{-1}$ was effective for *Cymbidium* orchids.

From the results obtained it may be concluded that wild *C. faberi* plants cannot tolerate either strong or weak light, indicating that it is not well adapted to light strength. The natural distribution of wild *C. faberi* species in Qinling Mountains shows that this orchid is not found in deep shade or open sunlight. Commercial orchid can be produced in the greenhouse where plant growth environment can be artificially controlled. Light is one of the important environmental factors that affect the growth and development of orchids. The research results of this paper show that the optimum illumination conditions for *Cymbidium* orchids between $25.78 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and $384 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$.

Acknowledgements

The authors are grateful for financial support from the State Forestry and Grassland Administration of China (No. 2016-46) and Forestry Department of Shaanxi Province (No. 2013-KJ01) for this study.

References

- Cai SZ, Li X, Pan YZ, Li J, Hu TX and Ye C 2013. A study on photosynthetic characteristics and growth and development of iris japonica under different illumination. *Acta Prataculturae Sinica*. **22**(2): 264-272.
- Gomes F, Oliva M, Mielke M, De A F and Leite H 2006. Photosynthetic irradiance-response in leaves of dwarf coconut palm (*Cocos nucifera* L. 'nana', Areaceae): comparison of three models. *Sci Hortic*. **109**: 101-105.
- Hou Y, Pan YZ, Jiang BB, Yang H, Zhou X and Li JY 2011. Diurnal variation of photosynthetic characteristics on calla lily (*Zantedeschia hybrida*). *Hubei Agricultural Sciences* **50**: 2689-2693.
- Jin T, Fu B, Liu G, Hu C, Su C and Yu L 2011. Diurnal changes of photosynthetic characteristics of hippophae rhamnoides and the relevant environment factors at different slope locations. *Acta Ecol Sin*. **31**: 1783-1793.
- Kim YJ, Yu DJ, Rho H, Runkle ES, Lee HJ and Kim KS 2015. Photosynthetic changes in cymbidium orchids grown under different intensities of night interruption lighting. *Sci Hortic*. **186**: 124-128.
- Li P, Gao H, Zou Q, Wang T and Liu Y 2005. The photosynthetic characteristics of five species of cymbidium. *Acta Horti Sin*. **32**: 151-154.
- Li Z, Zhou X, Chen J, Lei G and Du X 2012. Photosynthetic characteristics of drynaria fortunei and its relation to environmental factors. *Journal of Chinese Medicinal Materials*. **35**: 347-351.
- Liu GH, Li K, Sun YY, Hou R and Yan H 2014. Study of photosynthetic characteristics of dendrobium devonianum. *Int. J. Behav. Dev*. **27**: 265-269.
- Niu G, Kozai T and Kitaya Y 1996. Simulation of the time courses of CO₂ concentration in the culture vessel and net photosynthetic rate of cymbidium plantlets. *Trans. ASAE*. **39**: 1567-1573.
- Thornley JHM. 1998. Dynamic model of leaf photosynthesis with acclimation to light and nitrogen. *Ann. Bot*. **81**: 421-430.
- Yang XJ, Ying WU, Teng WJ and Yuan XH 2014. Daily and seasonal variation of photosynthetic characteristics of carex leucochlora. *Pratacultural Science* **31**: 102-107.
- Zeng S, Wu K, Zhang J, Chen Z and Duan J 2013. Advance on research of breeding and hybridization of Chinese orchid. *Chinese Wild Plant Resources* **32**: 1-5.

- Zhang J, Zhang Z, Zha T, Chen J, Sun G, Liu C, Cui L, Chen J and Shen L 2006. Physiological regulations of photosynthesis in a poplar plantation on a sandy soil. *Acta Ecol Sin.* **26**: 1523-1532.
- Zhang Q, Bai H, Hua S and Zhang S 2010. Spatial-temporal changes of forest landscape types in the eastern and western counties of Qinling Mountain during the last 30 years. *Huanjing Kexue Xuebao.* **30**: 1101-1106.
- Zhang SH, Liang SW, Zhong J H, Yan TD and Wang Y 2012. Comparative analysis of ten different geographical strains of *paris polyphylla* var. *yunnanensis* based on photosynthesis. *Yunnan Agric Univ.* **27**: 708-715.
- Zhang X and Xu D. 2000. Seasonal changes and daily courses of photosynthetic characteristics of 18-year-old Chinese fir shoots in relation to shoot ages and positions within tree crown. *Sci. Silvae Sin.* **36**: 19-26.
- Zhang YY, Fang ZM, Huang WT, Zeng SJ, Kun LW, Zhang JX and Duan J 2014. Study on change of leaf morphology and photosynthetic characters of three *paphiopedilum* species introduced in south China. *Guangdong Agricultural Sciences* **41**: 92-95.

(Manuscript received on 14 June, 2018; revised on 7 September, 2018)