Chapter

The Photosynthetic Characteristics of Wild *Cymbidium faberi* in the Qinling Mountains of Central China

Junyang Song and Ning Zhang

Abstract

The large flowers of orchids make them popular as cultivated plants. Seven species of orchids in the genus *Cymbidium* (Orchidaceae) have been crossbred 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 μmol m^{-2} s^{-1}, respectively. The result provides reference for cultivation management especially in light management of *Cymbidium*.

Keywords: *Cymbidium faberi*, photosynthetic characteristics, Qinling mountains, light compensation point, light saturation point

1. Introduction

Cymbidium faberi (Orchidaceae) is one of the several traditional and famous orchid flowers in China. The Chinese have cultivated orchids for more than 2500 years. Most scientists currently recognize seven *Cymbidium* species in China: *C. sinensis* (Jackson ex Andr.) Willd., *C. ensifolium* (L.) Sw., *C. goeringii* (Rchb. f.), *C. faberi* Rolfe., *C. kanrau* Makino., *C. lianpan* Tang and F.T. Wang ex Y.S. Wu, and *C. longibracteatum* W.S. Wu & S.C. Chen [1]. 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 and 105°30′–110°05′E, run through the

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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 researchers have been interested in the photosynthetic characteristics of various plants in the Orchidaceae [2–8], whereas few studies have addressed the growth of *C. faberi* [3], especially for those plants growing 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 (CO_2) concentration, the light saturation point (LSP), and the light compensation point (LCP). The data presented in this study provide a foundation for cultivation management of *Cymbidium* orchid and the conservation of wild *C. faberi* in Qinling Mountains.

2. Materials and methods

2.1 The site of experiment

The experiment was established at Qianjiaping Village, Shangnan County, Shaanxi Province, China, and located in the eastern part of the Qinling Mountains at 33°20′42.7″N, and 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, 41.3, and −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 hours of sunshine annually and a frostless period of 216 d; climatic data were collected between 1978 and 2008 [9].

2.2 The measurement of daily photosynthesis

The net photosynthetic rate (P_n, μmol m^{-2} s^{-1}), effective photosynthetic radiation (*PAR*, μmol Photons m^{-2} s^{-1}), stomatal conductance (G_s, mol m^{-2} s^{-1}), transpiration rate (T_r, mmol m^{-2} s^{-1}), and intercellular CO_2 concentration (C_i, μmol 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 the five randomly selected plants at the experiment site. The measuring time started at 08:00 and continued until 18:00 with hourly measurements taken. Each measurement was repeated 10 times.

2.3 The measurement of photosynthesis response

The photosynthetic responses were measured between 09:00 and 11:00 am on clear sunny days in April 2016 using the method of Gomes et al. [10]. The following

criteria were employed: the CO_2 concentration in leaf chamber was 375 μmol/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, and 0 μmol m^{-2} s^{-1} during the tests using a 6400-02B LED light source that was designed to also capture data automatically. Each measurement of five samples was replicated 10 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 [11]. The linear regression of the net photosynthetic rate to light intensity was calculated under 0–60 μmol m^{-2} s^{-1} of photosynthetically active radiation. The slope of the linear equation was the initial quantum yield. The light compensation point (LCP) and light saturation point (LSP) of wild *C. faberi* were calculated based on the curve of the photosynthetic response.

2.4 Data analysis

Data processing and drawing were conducted using Microsoft Excel 2003. The linear regression and correlation analyses were carried out using SPSS17.0.

3. Results and analysis

3.1 The daily patterns of net photosynthetic rate and photosynthetically active radiation

The net photosynthetic rate of wild *C. faberi* increased starting from 08:00 with an initial peak of 1.64 μmol m^{-2} 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 μmol m^{-2} 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 μmol m^{-2} s^{-1} followed by a decrease to 0.30 μmol m^{-2} s^{-1} at 18:00 (blue curve in **Figure 1**).

In contrast, the effective photosynthetic radiation gradually increased from 08:00 to a maximum of 600.21 μmol m^{-2} s^{-1} at 12:00. After 12:00, it gradually decreased to 140.41 μmol m^{-2} s^{-1} at 18:00 (red curve in **Figure 1**). When the effective photosynthetic radiation reached peaked at noon, the net photosynthetic rate decreased to its second lowest rate of 0.36 μmol m^{-2} s^{-1} (**Figure 1**).

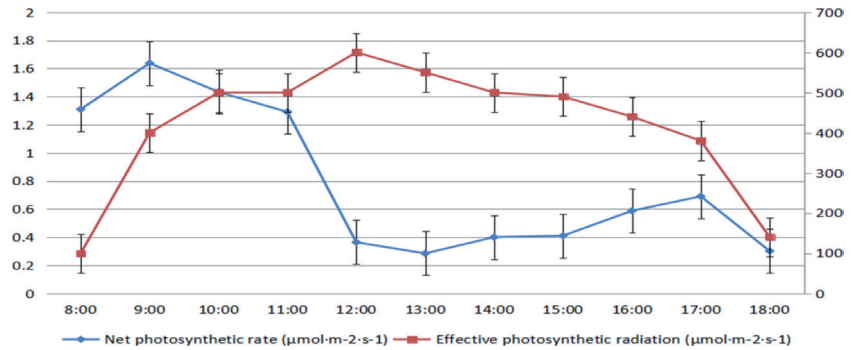


Figure 1.
The daily patterns of net photosynthetic rate and effective photosynthetic radiation in Cymbidium faberi (the error bar is standard deviation).

3.2 The relationship between net photosynthetic rate and stomatal conductance

The daily changes of stomatal conductance of wild *C. faberi* followed the same pattern as did the net photosynthetic rate (**Figure 2**). The first peak (maximum 0.0160 mol m^{-2} s^{-1}) in stomatal conductance occurred at 09:00 as did the peak in the net photosynthetic rate; however, the second peak (0.0060 mol m^{-2} s^{-1}) occurred at 16:00, 1 hour earlier than that of the net photosynthetic rate. In addition, the lowest stomatal conductance (0.0027 mol m^{-2} s^{-1}) was observed at 12:00, 1 hour earlier than that of the net photosynthetic rate (**Figure 2**). The very stomatal conductance and net photosynthetic rate were significantly correlated (R = 0.913 at P < 0.01).

3.3 The relationship between net photosynthetic and transpiration rates

The daily changes in the transpiration rate of *C. faberi* also showed a double-peak pattern with the highest peak of 0.23 mmol m^{-2} s^{-1} at 9:00 and a second peak of 0.20 mmol m^{-2} s^{-1} at 16:00 (red curve in **Figure 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 net photosynthetic rate, the daily changes in the transpiration rate showed a relative flat pattern.

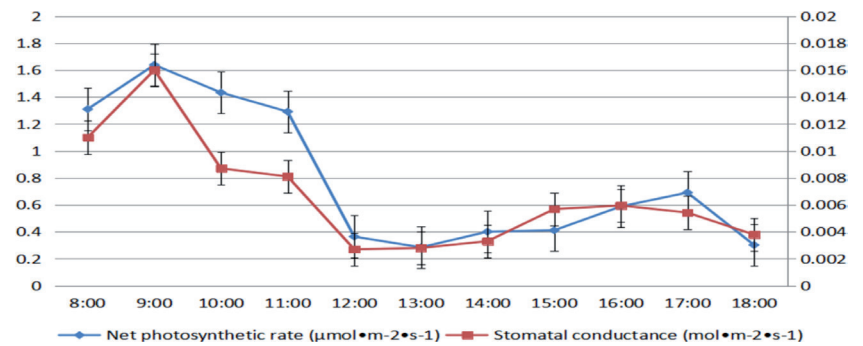


Figure 2.
The relationship between net photosynthetic rate and stomatal conductance in Cymbidium faberi during a typical day (the error bar is standard deviation).

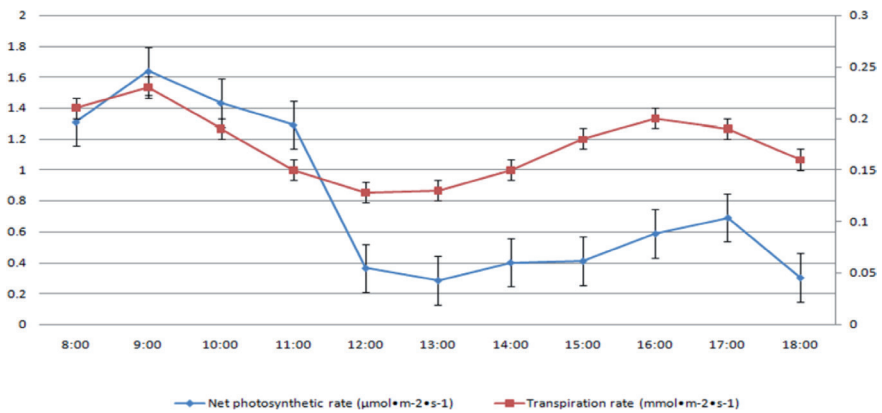


Figure 3.
The relationship between net photosynthetic rate and transpiration rate in Cymbidium faberi during a typical day (the error bar is standard deviation).

3.4 The relationship between net photosynthetic rate and intercellular CO_2 concentration

The daily changes of the intercellular CO_2 concentration of *C. faberi* (red curve in **Figure 4**) had a pattern different from that of the net photosynthetic rate. The intercellular CO_2 concentration started at 278.2 μmol mol^{-1} at 08:00 and decreased to 156.5 μmol mol^{-1} at 11:00. Around noon, the intercellular CO_2 concentration peaked at 315.1 μmol mol^{-1} and then fell dramatically to 171.8 μmol mol^{-1}. After 13:00, the intercellular CO_2 concentration gradually decreased to the lowest value of 140.3 μmol mol^{-1} at 17:00. From 17:00, the intercellular CO_2 concentration began to increase and reached 238.2 μmol mol^{-1}at 18:00.

The intercellular CO_2 concentration had an opposite pattern of change when compared with that of the net photosynthetic rate although this correlation was not significant ($R = -0.094$; **Figure 4**). The intercellular CO_2 concentration decreased with an increase in the net photosynthetic rate and vice versa.

3.5 Seasonal variation of net photosynthetic rate

Figure 5 shows that the patterns of the net photosynthetic rate in both spring and winter exhibited double peaks. However, the peaks of the net photosynthetic rate occurred at different times when comparing those of winter to those of spring. For example, the highest peaks in winter and spring, that is, peaks of 0.82 and 1.64 μmol m^{-2} s^{-1},

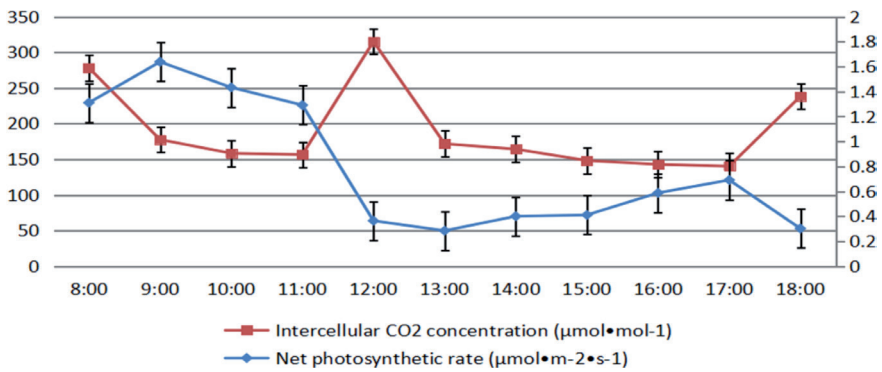


Figure 4.
The relationship between net photosynthetic rate and intercellular carbon dioxide concentration in Cymbidium faberi during a typical day (the error bar is standard deviation).

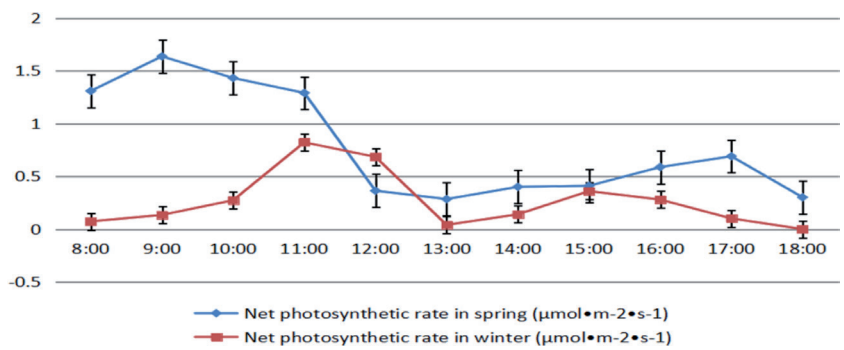


Figure 5.
Seasonal variation of net photosynthetic rate in Cymbidium faberi during a typical winter and spring day (the error bar is standard deviation).

occurred at 11:00 in winter and 09:00 in spring, respectively. The second peak of the net photosynthetic rate 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 (**Figure 5**). The average net photosynthetic rate of *C. faberi* in winter (0.26 μmol m^{-2} s^{-1}) was smaller than that in spring (0.79 μmol m^{-2} s^{-1}).

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

3.6 Photosynthetic response curve

Figure 7 shows that the changes in the photosynthetic response P_n-*PAR* curves showed a parabolic shape (**Figure 7**). When the effective photosynthetic radiation ranged between 0 and 60 μmol m^{-2} s^{-1}, the change of the net photosynthetic rate presented a linear increase. However, when the effective photosynthetic radiation was between 200 and 400 μmol m^{-2} s^{-1}, the net photosynthetic rate remained at a relatively high level with a maximum of 2.41 μmol m^{-2} s^{-1} at around 400 μmol m^{-2} s^{-1}. When the effective photosynthetic radiation was greater than 400 μmol m^{-2} s^{-1}, the net photosynthetic rate obviously began to decrease, showing a light suppression phenomenon.

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

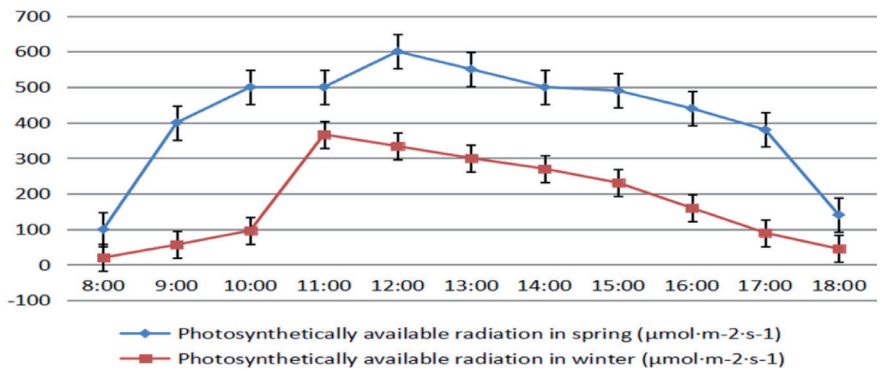


Figure 6.
Seasonal variation of effective photosynthetic radiation in Cymbidium faberi during a typical winter and spring day (the error bar is standard deviation).

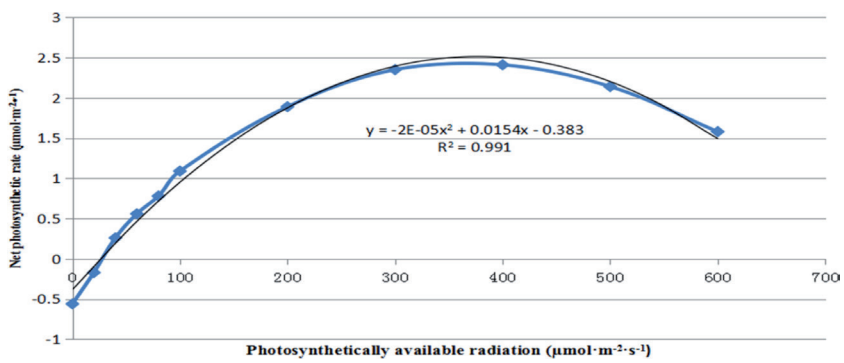


Figure 7.
Light responsive curve in Cymbidium faberi plotting photosynthetically available radiation against the net photosynthetic rate.

the effective photosynthetic radiation was 25.78 μmol m^{-2} s^{-1}, the net photosynthetic rate was zero. Also, when the effective photosynthetic radiation was 384 μmol m^{-2} s^{-1}, the net photosynthetic rate peaked (2.57 μmol m^{-2} s^{-1}). After the effective photosynthetic radiation reached to 384 μmol·m^{-2} s^{-1}, the net photosynthetic rate decreased, even when the effective photosynthetic radiation increased. Therefore, the light compensation points (LCP) and the light saturation points (LSP) of wild *C. faberi* in the Qinling Mountains were 25.78 and 384 μmol m^{-2} s^{-1}, respectively.

4. Discussion

Photosynthesis is one of the important factors for plant adaptation, substance accumulation, and metabolism. It also serves as the critical factor influencing plant growth, development, and productivity [12, 13]. However, photosynthesis is influenced by both genotype and environment as well as their interaction [14]. Multiple factors in the environment are known to interact and affect plant photosynthesis [15]. In the present study, the daily pattern of change in the net photosynthetic rate 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 [15]. 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 net photosynthetic rate showed this rate was lower in winter than in spring in wild *C. faberi*. The peak net photosynthetic rate in spring occurred 2 hours earlier than in winter, but the second high peak was delayed by 2 hours in spring when compared with that in winter. These results are similar to those in *Carex leucochlora* [14]. The seasonal changes in the net photosynthetic rate in winter and spring were mainly caused by seasonal differences in temperature and light intensity, suggesting that the net photosynthetic rate is significantly related to environmental conditions.

The analysis of the relationship between the net photosynthetic rate and other physiological factors suggests that the net photosynthetic rate 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. [16] and Zhang et al. [13] found that the net photosynthetic rate of *Paris polyphylla* var. *yunnanensis* was positively correlated with stomatal conductance, while Li et al. [17] found that these two were negatively correlated. Stomata provide a channel for the exchange of gasses 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 [18]. The net photosynthetic rate of the wild *C. faberi* leaf decreased with a decrease in stomatal conductance, indicating that stomatal conductance is one of the causes 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 [19]. This study found that the LCP and LSP of wild *C. faberi* in Qinling Mountains are 25.78 and 384 μmol m^{-2} s^{-1}, respectively, compared to the 500 and 10 μmol m^{-2} s^{-1} in cultivated *C. faberi* species [3]. The difference of the LCP and LSP is the result of long-term adaptation to the environmental conditions under which the plants grew. Kim et al. [20] researched photosynthetic change in *Cymbidium* orchids grown under intensities of night interruption lighting. The results showed that photosynthetic photon flux of 120 μmol m^{-2} s^{-1} was effective for *Cymbidium* orchids.

In conclusion, wild *C. faberi* plants cannot tolerate either strong or weak light, meaning it is narrowly adapted to light strength. The natural distribution of wild *C. faberi* species in Qinling Mountains is in accordance with the results of this study in that it is not found in deep shade or open sunlight. Commercial orchids were produced in greenhouse where plant growth environment can be artificially controlled. The light factor of greenhouse can be regulated and controlled by grower easily based on the range and optimum value of light factors [21]. It is beneficial to the production of orchids. 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 are between 25.78 and 384 μmol m^{-2} s^{-1}. That is to say, light intensity should not be below 25.78 μmol m^{-2} s^{-1} and not higher than 384 μmol m^{-2} s^{-1}.

5. Conclusions

1. The daily variation of net photosynthetic rate of wild *Cymbidium faberi* shows double-peak curve both in winter and spring.

2. There was midday depression phenomenon in the diurnal variation of photosynthetic rate for wild *Cymbidium faberi*. It appears around 13:00 pm.

3. The stomatal conductance and the net photosynthetic rate of wild *Cymbidium faberi* were significantly correlated($R = 0.913$ at $P < 0.01$).

4. There was a correlation between the net photosynthetic and transpiration rates ($R = 0.659$ at $P < 0.05$).

5. The intercellular CO_2 concentration had an opposite pattern of change when compared with that of the net photosynthetic rate although this correlation was not significant ($R = -0.094$).

6. The light compensation points (LCP) and the light saturation points (LSP) of wild *C. faberi* in the Qinling Mountains were respectively 25.78 and 384 μmol m^{-2} s^{-1}.

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