

## Phenotypic Diversity of Photosynthetic Characteristics in 16 Cucumber Accessions Selected from the Core Collection

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**Abstract.** To investigate the phenotypic variation of cucumber photosynthesis, net photosynthetic efficiency of cucumbers were measured by LI-6400XT Portable Photosynthesis System. Non-rectangular hyperbolic model was adopted to fit the light response curve. We used 16 cucumber accessions selected from the core collection that consists of over 400 accessions. As a result, cucumbers show a moderate variance in the phenotype of light compensation point (*LCP*), light saturation point (*LSP*) and apparent quantum efficiency (*AQY*), dark respiration rate (*R<sub>d</sub>*), and maximum net photosynthetic rate (*A<sub>max</sub>*). In a detail, the coefficient of variation (*CV*) of *LCP* and *R<sub>d</sub>* is 48.97% and 48.09%, respectively, which is relatively high. In contrast, the *CV* values of *A<sub>max</sub>*, *LSP* and *AQY* are all smaller than 25%. These results help us get better understanding about the phenotypic variation of photosynthesis in cucumber germplasm.

### Introduction

The cucumber (*Cucumis sativus* L.) is an important vegetable in the world whose planting area is only the second to tomato [1]. A core collection of cucumber germplasm consisting of 473 accessions was established previously based on the genetic diversity study using over 4000 original collections from all over the world [2, 3]. Photosynthesis converts light energy into chemical energy and therefore is the bases of crop yield. Generally, dry matter weight ascribed to photosynthesis takes 90% - 95%, while that ascribed to root absorption takes only 5% to 10%. There is a positive correlation between photosynthetic rate and the plant dry matter accumulation ability [12]. Lots of studies have already demonstrated that light intensity and quality intensively affect the photosynthesis reaction and subsequently the plant growth rate [4]. To our best knowledge, few studies revealed the photosynthetic characteristics in cucumber germplasm so far. In this study, we investigated the photosynthetic traits of 16 cucumber accessions and thereafter calculated light compensation point (*LCP*), light saturation point (*LSP*), the apparent quantum efficiency (*AQY*), dark respiration rate (*R<sub>d</sub>*), and maximum net photosynthetic rate (*A<sub>max</sub>*).

### Materials and Methods

#### Plant Materials

A total of 16 cucumber accessions were selected from the core collection to perform the assay. These accessions are from India, Russia, Spain, Germany, America, Japan, as well as provinces of Xinjiang, Guizhou, Fujian, Henan, Shandong, Guangxi, Anhui,

Hubei, Sichuan, Yunnan in China. All the cucumber plants were grown in greenhouse at the same time in spring, 2015. The fifth top leaves of two month old plants were subjected to photosynthesis measurement.

### Light Response Curve Measurement

Photosynthetic characteristics were measured with a Portable Photosynthesis System LI-6400 (LI-COR Inc., USA). All parameters were measured between 10:00 A.M. and 11:00 A.M. The light-response curves of  $P_N$  with light intensity changing was made with the PAR setting values 1800, 1500, 1200, 1000, 800, 600, 400, 200, 150, 100, 75, 50, 25, 0 ( $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ ). The measurement was conducted under  $\text{CO}_2$  concentration of  $400 \mu\text{mol}\cdot\text{mol}^{-1}$ . Light response curve fitting was performed using non-rectangular hyperbolic model. The fitting formula was as follows [5]:

$$A = \frac{A_{max} \times PPDF \sqrt{(AQY \times PPDF + A_{max})}}{2k} - R_d \quad (1)$$

$A_{max}$ , the maximum net photosynthetic efficiency.  $A$ , net photosynthetic rate.  $AQY$ , apparent quantum efficiency.  $R_d$ , dark respiration rate.  $K$ , the optical response curve angle.  $PPDF$ , photosynthetically active radiation.

Light response curves were fitted using an iterative method to calculate the apparent quantum efficiency ( $AQY$ ), dark respiration rate ( $R_d$ ), maximum net photosynthetic rate ( $A_{max}$ ). The formula was as follows [6]:

$$A = AQY \times PPDF - R_d (PPDF \leq 200 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}) \quad (2)$$

In this formula, light compensation point ( $LCP$ ) was calculated when  $A$  is 0; light saturation point ( $LSP$ ) was calculated when  $A$  is  $A_{max}$ .

## Results and Discussion

### Light Response Curve Analysis

$P_N$  responses to PAR of the 16 cucumber species showed significant differences under the light intensity from 400 to 2400  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  (Fig. 1).  $P_N$  increased rapidly when PAR increased from 0 to 800  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ . Based on the light response curves, photosynthetic parameters ( $LCP$ ,  $LSP$ ,  $AQY$ ,  $R_d$ ,  $A_{max}$ ) were also calculated (Table 1). The  $A_{max}$  value ranges 7.801-18.119  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ . This value is lower to major cereal crops *e.g.* maize [7], rice [8] but comparable to most vegetables *e.g.* pepper [9], tomato [10].  $LCP$  and  $LSP$  are used to reflect the ability of plants to use light in low and high intensity [11, 12]. The  $LSP$  value ranges from 237.40 to 647.67  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ . The  $LCP$  value ranges from 2.401 to 29.453  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  and the average number is 16.241  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ , which is significantly lower than that in many other plant species [13]. This suggests that cucumbers are capable of adapting to weak light. Based on these above results, strong light intensity is in fact not necessary for cucumber growth although cucumbers are known as heliophile.  $AQY$  was calculated as the inclination of the initial slop of the light response curve of net photosynthesis. The value of  $AQY$  reflects potential plant photosynthetic capacity and energy use efficiency [14, 15]. Cucumber  $AQY$  value ranges 0.023-0.046 which is higher than most plant species. Plants usually have an  $AQY$  value of 0.03-0.05. The  $R_d$  value ranges 0.128-1.071  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ . Lower  $R_d$  value indicates higher ability to accumulate dry matters. However, many accessions that have higher photosynthetic rate like No. 16, No. 81,

and No. 97 etc. also have higher  $R_d$  value. These cucumbers have higher growth rate due to the higher rate of metabolism.

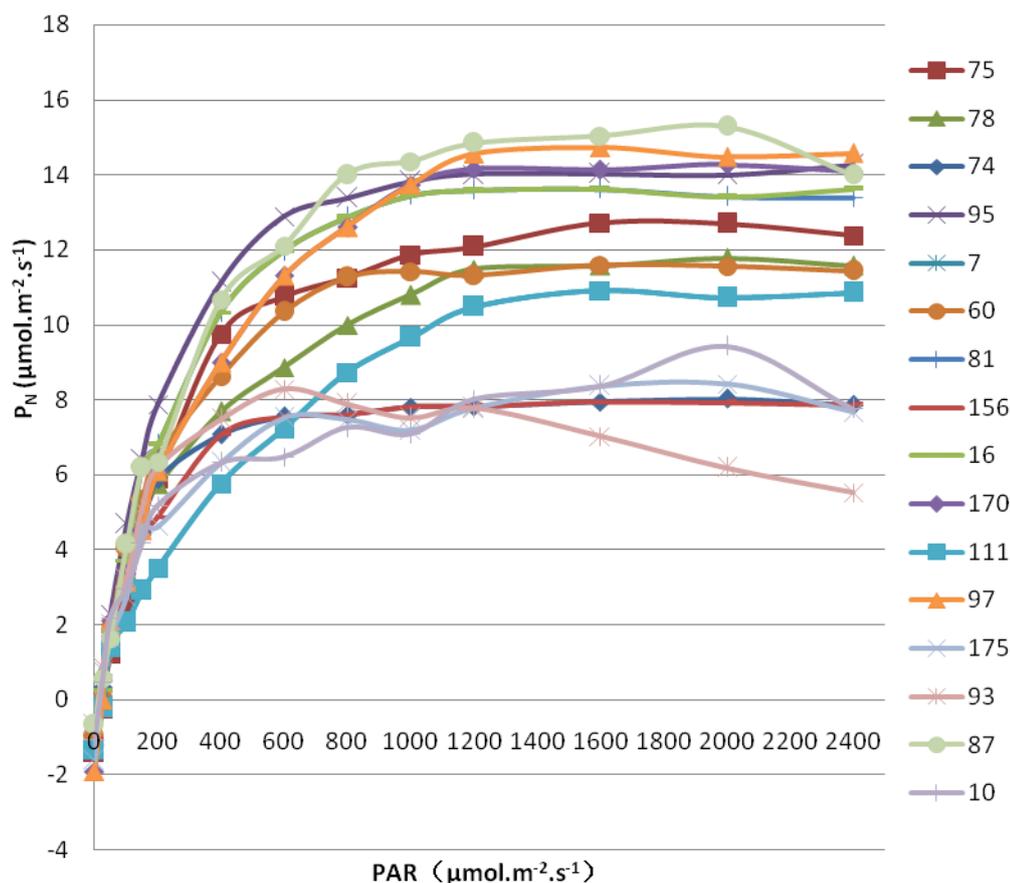


Figure 1. Responses of the net photosynthetic rate ( $P_N$ ) to photosynthetically active radiation (PAR) in the 16 cucumber accessions.

Table 1. Photosynthetic parameters of light-response curve

Accession No	LCP ( $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ )	LSP ( $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ )	AQY	$R_d$ ( $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ )	$A_{max}$ ( $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ )
7	27.057	511.435	0.023	0.620	14.212
16	15.537	393.530	0.041	0.637	15.498
60	14.094	366.588	0.038	0.537	13.430
81	19.639	390.138	0.042	0.827	15.589
97	24.436	518.880	0.037	0.902	18.119
111	27.057	647.668	0.023	0.620	14.212
156	9.799	326.089	0.029	0.283	9.141
170	23.524	494.768	0.037	0.870	17.436
74	15.653	288.130	0.033	0.518	9.019
75	29.453	425.854	0.036	1.071	14.429
78	8.523	426.076	0.033	0.282	13.821
95	13.340	368.991	0.046	0.608	16.143
93	2.401	237.398	0.033	0.128	7.801
87	6.624	457.851	0.038	0.248	16.921
10	7.825	341.570	0.029	0.228	9.712
175	14.895	355.575	0.029	0.438	10.016

### Dispersion of Photosynthetic Parameters TRAITS

Using SPSS software, traits dispersion of photosynthetic parameters were analyzed (Table 2). The dispersion rate of  $LCP$ ,  $LSP$ ,  $AQY$ ,  $R_d$ , and  $A_{max}$  are 48.969%, 23.820%,

17.647%, 48.094%, and 23.766%, respectively. These results indicate there is a big difference in the phenotypic variance of the photosynthesis parameters. Considering the assayed cucumber accessions are from different countries and represent a genetic diversity in cucumber germplasm, we suppose that cucumbers have evolved a big variance to adapt to weak light condition (*LCP*) but not strong light condition (*LSP*). According to other reports, the coefficient of variation of major cucumber agronomic traits ranges 9%-88% [16]. Generally speaking, there is a moderate variance in the phenotype of cucumber photosynthesis.

Table 2. Photosynthetic parameters of light-response curve

	<i>LCP</i>	<i>LSP</i>	<i>AQY</i>	$R_d$	$A_{max}$
Average	16.241	409.409	0.034	0.551	13.469
SD	7.953	97.523	0.006	0.265	3.201
CV (%)	48.969	23.820	17.647	48.094	23.766

SD, Standard deviation; CV, coefficient of variation; CV=SD/Average.

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