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ORIGINAL ARTICLE

Evaluation of Photosynthetic Ability in Two Representative Evergreen Broad-leaved Tree Species in Korea

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Abstract

To maintain a rich biological diversity is important to develop for biomaterial resources such as Korean evergreen broad-leaved tree species, the distribution of which is restricted to the southern part of Korean peninsula. We assessed photosynthetic characteristics of *Quercus acuta* and *Castanopsis sieboldii*, the representative evergreen broad-leaved trees in Korea, in order to establish a basis for conservation strategy related to distributional change in evergreen broad-leaved tree species according to climate change. Photosynthetic characteristics were evaluated in the sun and shade leaves of the two species. Sun leaves in both species revealed higher light compensation point and maximum photosynthetic rate compared to the shade leaves. In addition, photosynthetic rate was higher in *Q. acuta* than *C. sieboldii*, which was supported by a higher leaf nitrogen content and leaf mass per area. Water use efficiency was also higher in *Q. acuta* as compared to that in *C. sieboldii*. Similar photosynthetic rate, however, was shown in photosynthetic response to CO_2 concentration in the intercellular space. These results suggest that both species could respond differently to the changing environmental factors including climate change, suggesting the possibility of distributional changes resulting from a differential growth rate.

Key words : Evergreen broad-leaved tree, Leaf mass per area, Leaf nitrogen content, Photosynthesis

1. Introduction

Climate change affects productive process and performance of plants. In particular, increasing CO_2 concentration and air temperature lead to change of photosynthesis and plant water use traits and, in turn, result in matter production change of plants. In natural forest, global warming can accelerate difference in death rate and recruitment success between species (Ibanez et al., 2008; Peltier and Ines, 2015), resulting in distributional change of tree species.

Vegetation in Korea is roughly classified into three representative types (Kim, 1992). In northern part of Korean peninsula coniferous tree species such as *Picea jezoensis* and *Abies hollophylla* makes up subalpine coniferous forest. In the middle part region broad-leaved deciduous forest composed of *Quercus mongolica*, *Rhododendron schlippenbachii* and *Lindera obtusiloba* is distributed over a wide area, forming representative cool temperate forest. On the other hand, warm temperate forest that is mainly composed of evergreen broad-leaved tree species is distributed with a narrow area in southern part of Korean peninsula due to the cold of winter. Besides, its distribution is scattered in many islands far away from main land of Korea. Thus, evergreen broad-leaved

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tree species is very important in terms of conservation of biological diversity in Korea. In recent, the extension of distribution in some evergreen broad-leaved tree species into northern region of the peninsula has been reported (Park et al., 2010). Considering isolated population of a species is easy to extinct accumulation of information on ecophysiological characteristics for evergreen broad-leaved tree species is essentially needed to establish a basis for conservation plan in Korea.

We assessed photosynthetic traits in the two representative evergreen broad-leaved tree species to find a clue to predict their distributional change under climate conditions.

2. Materials and Methods

2.1. Study site and species

The study was conducted in Wando-arboretum located at Wando Island, Jeollanam-do province, Korea (N34°21'25", E126°40'31"). Wando-arboretum is located at hillside of Mt. Baegunbong with 600 m above sea level in peak. An average annual precipitation in Wando area is about 1,600 mm (Korea Meteorological Administration, 2015). Mean annual temperature is above 15℃, and it remains over 0℃ even in January. As a result, vegetation in this area shows the representative warm temperate forest characteristics, occupied by evergreen broad-leaved tree species such as *Camellia japonica*, *Quercus acuta* (*Q. acuta*) and *Castanopsis sieboldii*. (*C. sieboldii*). Among tree species we selected two species as plant materials because these species were remained in a state of nature with high integrity without any extensive disturbance like artificial thinning for management. We categorized plant materials into two groups; sun leaf is a group of leaves exposed to full sunlight by facing outward of canopy. Shade leaf is a group of leaves exposed to shaded light condition inside canopy. Three branches from each of three individuals were randomly sampled per species. Branches about 1 m long with leaves were cut and then immediately recut the base of them under air-removed water in a bucket to protect disconnection of sap in branch. Branches were capped with dark-colored plastic bag and then transported to laboratory for measurements of photosynthesis. All measurement was performed within three days after sampling

2.2. Gas exchange measurement and leaf characteristics

Leaf gas exchange rate was measured with potable photosynthesis apparatus (Li-6400, Li-Cor, Lincoln, NE). Phtosynthetic light responses to Photosynthetic Photon Flux (PPF) were measured by increasing PPF in seven steps from 0 to 2,000 μmol/m^2/s under 400 ppm in CO_2 concentration in the chamber. The photosynthetic response curve to intercellular CO_2 concentration (Ci) was also constructed in eight steps by increasing CO_2 concentration with CO_2 injector (LI 6401-01) under 1,000 μmol/m^2/s PPF conditions. LED (LI 6400-2B, Li-Cor, Lincoln, NE) light was used for measurements. During all measurements of temperature and relative humidity in the chamber were maintained 25℃ and above 50%, respectively. From sampled branches five leaves per species were selected for chlorophyll measurement. Another five leaves were sampled for measurements of Leaf Mass per Area (LMA) and Leaf Nitrogen Content (LNC). Chlorophyll content was determined with absorbance at 663.8 and 646.8 nm using spectrophotometer according to Porra et al. (1989) after chlorophyll extraction with dimethylformamide (DMF) for 2 days in the refrigerator. For the measurement of LMA and LNC leaf area was determined using area meter (AAM-8, Hayashi Denkou, Tokyo, Japan) and then leaf dry mass was determined after drying at 80℃ for 48 hrs. LNC was determined with semi-microkjeldahl system (VA-SA-1, MRK. Tokyo, Japan). Statistical

analyses were performed with the SPSS software package (SPSS 24.0 2017) for Windows.

3. Results and Discussion

3.1. Photosynthetic traits

Light is one of the critical environmental factors in plants because matter production affects survival, growth, reproduction and distribution of plants. As a result, light environment in habitat leads to the differentiation of sun and shade plants and has brought development of sun and shade leaves in even an individual tree (Givnish, 1988). Photosynthetic rates of *Q. acuta* and *C. sieboldii* to PPF were shown in Fig. 1. Sun leaves in *Q. acuta* tree species showed higher photosynthetic rates than those in shade leaves. *C. sieboldii* also showed higher photosynthetic rates in sun leaves than shade leaves though the difference between them was not strikingly apparent compared to *Q. acuta* (Fig. 1). These results indicate that there is a leaf differentiation according to light environments inside and outside of canopy in both tree species. Pmax of *Q. acuta* in sun leaves was 6.40 μmol/m^2/s, whereas Pmax of *C. sieboldii* only reached about 73% of that of *Q. acuta* (Fig. 1). Light Compensation Point (LCP), light saturation point and P_{max} are shown in Table 1. In LCP, similar values were observed in both species (Table 1). On the other hand, Pmax of shade leaves in *C. sieboldii* showed higher than that in *Q. acuta* (Table 1). Photosynthetic characteristics shows strong correlation with PPF irrespective of leaf position, indicating the plasticity of leaf characteristics (Gonz et al., 2001; Iio et al., 2005). Thus, different photosynthetic response between sun and shade leaves and the difference between tree species must be related to the plasticity of leaf characteristics of species. Fig. 2 shows photosynthetic responses to intercellular CO_2 concentration in the leaf. The carboxylation rates are also higher in *Q. acuta* than in *C. sieboldii* irrespective of sun and

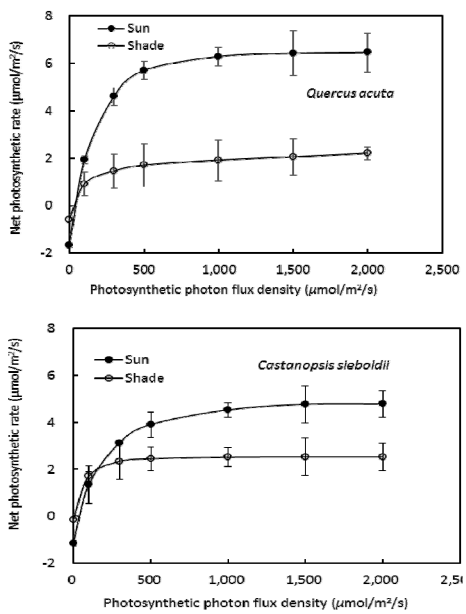

Fig. 1. Light response curves in sun and shade leaves of *Q. acuta* and *C. sieboldii*. Bars indicate standard errors (n=5).

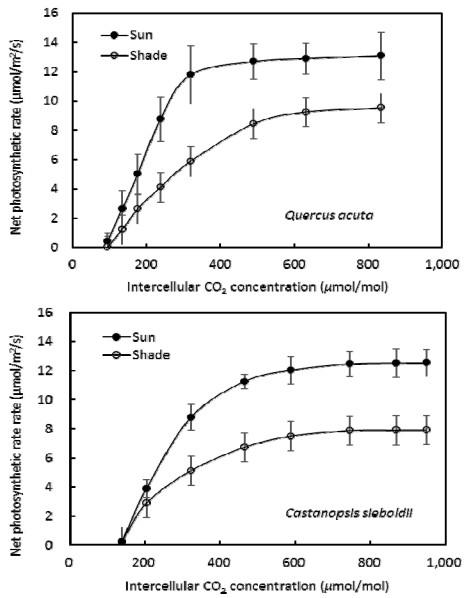

Fig. 2. Photosynthetic rate to CO_2 concentration at intercellular space (A-Ci) in sun and shade leaves of *Q. acuta* and *C. sieboldii*. Bars indicate standard errors (n=5).

Table 1. Photosynthetic characteristics of *Quercus acuta* and *Castanopsis sieboldii* trees. Values are means ± se (n=5). Different letters indicate significant difference at P ≤ 0.05

Species	*Q. acuta*		*C. sieboldii*	
Photosynthetic parameters	Sun	Shade	Sun	Shade
Light compensation point (μmol/m^2/s)	54.7±4.06a	40.0±4.16ab	54.2±3.49a	23.9±6.87b
Light saturation point (μmol/m^2/s)	1080±146a	873 ±146b	1143±101a	687±48.2b
Maximum photosynthetic rate (μmol/m^2/s)	6.40±0.12a	2.06±0.08b	4.72±0.21c	2.52±0.13d

shade leaves (Fig. 2). Leaf photosynthesis rate under full sunlight strongly depends on CO_2 concentration (Pfanz et al., 2007). However, at CO_2 level of 300-400 ppm photosynthesis is restricted by CO_2 concentrations, whereas RuBP concentration in stroma limits photosynthetic rate at over 400 ppm of CO_2 concentrations (Von Caemmerer and Farquhar, 1981). Thus, A-Ci curve like Fig. 2 can give an information related to the effect of stomatal conductance (Farquar and Sharkey, 1985), relationship between maximum photosynthetic rate and environmental condition, rubisco activity, and RuBP reduction ability (Fischer et al., 1997). Photosynthesis is very complicated process acting together with several factors. The first process of photosynthesis begin from light absorption in chlorophyll of a leaf. Both species showed higher chlorophyll contents in sun leaves than in shade leaves (Table 2). Thick leaf, high chlorophyll a/b ratio, and high nitrogen contents per area in sun leaf is favorable characteristics functionally and structurally for strong light use (Evans and Seemann, 1989). On the other hand, shade leaf is characterized by big chloroplast, many thylakoids per granum, and high specific leaf area, which are developed to adapt to weak light conditions (Fahl et al., 2015). The combination of these characteristics in sun and shade leaves is the results of adaptation of leaf to light environment (Ashton, 1992). Contrary to the results of

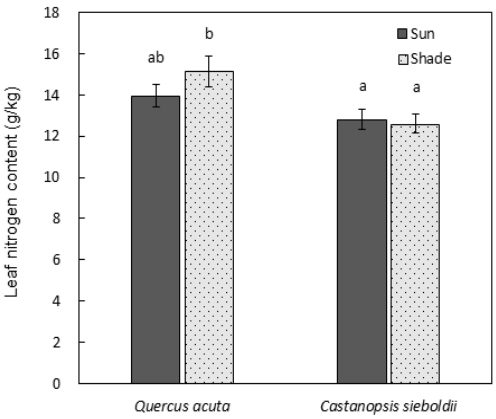

Fig. 3. Leaf Nitrogen Content (LNC) in sun and shade leaves of *Q. acuta* and *C. sieboldii*. Bars indicate standard errors (n=5). A Different letter indicates significant difference at p ≤0.05.

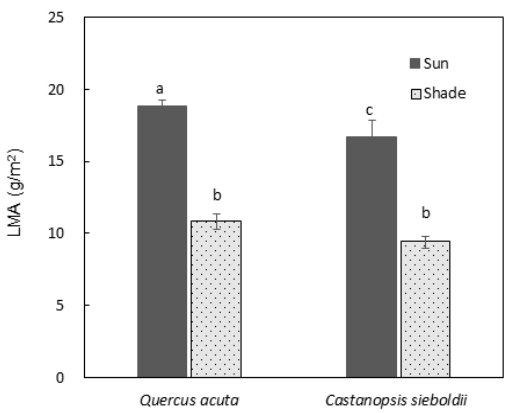

Fig. 4. Leaf Mass per Area (LMA) in sun and shade leaves of *Q. acuta* and *C. sieboldii*. Bars indicate standard errors (n=5). A Different letter indicates significant difference at p ≤0.05.

Table 2. Chlorophyll contents of *Quercus acuta* and *Castanopsis sieboldii*. Values are means ± se (n=5). Different letters indicate significant difference at P ≤ 0.05

Species	Type	Chl a (g/m^2)	Chl b (g/m^2)	Chl a+b (g/m^2)	Chl a/b (g/m^2)
Q. acuta	Sun	13.9±0.92a	5.57±0.21a	19.5±1.13a	2.48±0.07a
	Shade	10.8±0.88b	5.02±0.26a	15.8±1.14a	2.13±0.06b
C. sieboldii	Sun	28.0±2.42b	12.1±0.73b	40.2±3.13b	2.29±0.08b
	Shade	18.2±1.35a	8.70±0.58c	26.9±1.91c	2.09±0.05b

photosynthetic rate *C. sieboldii* showed higher chlorophyll contents compared to those in *Q. acuta* (Table 2). In chlorophyll a/b ratio, however, *Q. acuta* maintained high values in both sun and shade leaves. This discrepancy must be resulted from the complexity of interactions involved in biochemical process of photosynthesis (Kenzo et al., 2004; Iio et al., 2005; Yasumura et al., 2006). Besides, various environmental factors such as leaf thickness (Koike, 1988, 1989), leaf nitrogen content (Reich et al., 1999) and mesophyll structure (Kenzo et al., 2004) also affect maximum photosynthetic rate. In particular, it is well known that leaf nitrogen content affects photosynthetic capacity, and strong correlation between leaf nitrogen content and light availability (Hikosaka, 2004). Fig. 3 shows LNC in sun and shade leaves of the two species. Considering that Pmax is correlated with leaf nitrogen (Yasumura et al., 2006), and changes of rubisco and chlorophyll contents were strongly correlated to leaf nitrogen, the difference of Pmax in sun leaves between the two species may be due to low leaf nitrogen content in *C. sieboldii* (Figs. 1, 3). Light availability inside and outside canopy has brought the difference in LMA between sun and shade leaves (Fig. 4). LMAs of sun leaves in both species indicated significantly higher than those in shade leaves. LMA indicating leaf thickness is linked to efficient light use under high light conditions (Atwell et al., 1999). In addition, sun leaves in *Q. acuta* showed higher LMA compared to *C. sieboldii*. This is strongly supported by the fact that LMA and canopy leaf characteristics contribute to increase of Pmax (Kenzo et al., 2004; Takashima et al., 2004; Iio et al., 2005). Sun leaves in *Q. acuta* indicated higher WUEs than those in C. sieboldii (Fig. 5). This must result from the difference in LNC and LMA (Figs. 3, 4).

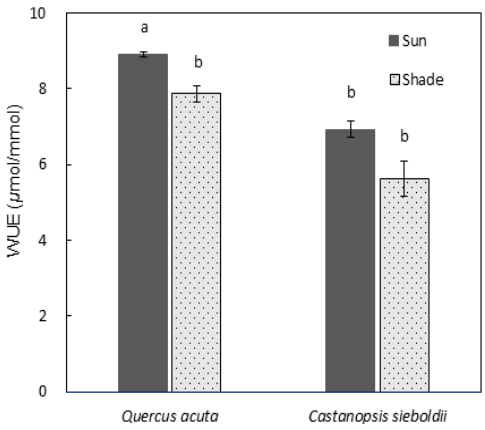

Fig. 5. Water Use Efficiency (WUE) in sun and shade leaves of *Q. acuta* and *C. sieboldii*. Bars indicate standard errors (n=5). A Different letter indicates significant difference at p ≤0.05.

4. Conclusion

Evergreen broad-leaved tree species is limitedly distributed in southern part of Korean peninsula. Particularly, their distribution is scattered around some islands with narrow area. Climate change accelerates plant distributional change toward northern area in Korea. In this study we evaluated photosynthetic ability of the two representative evergreen broad-leaved tree species to judge the

possibility of distributional change under changing climate conditions. Both species responded differently in photosynthesis to light and CO_2 conditions. As photosynthetic traits were assessed *Q. acuta* showed a higher photosynthetic ability than *C. sieboldii* in sun leaves, which was supported by high LNC and LMA.

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