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Measurement of ecological niche of *Quercus aliena* and *Q. serrata* under environmental factors treatments and its meaning to ecological distribution

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Abstract

Quercus aliena and *Q. serrata* are both occur as natural vegetation alongside natural freshwater bodies of the southern Korea Peninsula. *Q. serrata* dominates over *Q. aliena* as secondary forest vegetation in the present day. In order to explain these natural distributional traits of the oak species, we conducted some experiments with oak seedlings which treated with major important environmental resources, including light, moisture and nutrients, under controlled conditions. We then measured the ecological niche breadths and overlap from 15 eco-morphological characteristics. The ecological niche breadth of *Q. aliena* and *Q. serrata* were higher in terms of the nutrient factor applied, but was lower terms of light. The niche breadth of *Q. serrata* was wider than that of *Q. aliena* in light and moisture exposure. On the other hand, the niche breadth of *Q. aliena* was similar with that of *Q. serrata* in terms of the nutrient factor applied. These results imply that *Q. serrata* has a broader ecological distribution in over a wider variety of light and moisture environments than that of *Q. alien*. Ecological niche overlap between two oak species was the widest in terms of the light treatment factor applied, and narrowest in terms of moisture. This response pattern was also verified by cluster and principle component analysis. These results suggest competitive interactions between *Q. serrata* and *Q. aliena* seedlings may be higher for light resources than moisture or nutrient resources, and that *Q. serrata* is more shade tolerant than *Q. aliena*.

Key words: distribution, environmental factor, multivariate analysis, niche breadth, niche overlap

INTRODUCTION

Ecological niche had been introduced by Grinnell (1917) who interpreted it as the ultimate distributional unit of a species in a spatial sense. Later, the ecological niche was used explaining the niche functional aspects when describing an organism's place in its biotic environment in connection with its nutrition (Elton 1927). Hutchinson (1957) reported that niche is the sum of all the environmental factors acting on the organism, a region of an n-dimensional hypervolume. Ecological niche was also defined as the functional role or status of the organism within its community and ecosystem resulting from the organism's structural adaptations, physiological responses, and specific behavior (Odum 1969).

Ecological niche has been divided into two categories, ecological niche breadth and ecological niche overlap. The niche breadth of a given species and for a given parameter is the range of environmental tolerance between the maximum and minimum of that parameter, under which the species may survive. It is the scope of tolerance and is dependent on the response of a species to

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the environmental factor which it describes. Species with small niche breadths refer to species with narrower distributions within nature, and smaller sizes of populations. whereas an organism with a larger niche breadth refers to its wider range in nature and larger size of populations owing to its adaptability to changing environments (Pianka 1983).

Ecological niche overlap means a similar response to an environmental factor or the utilization of the same natural resource by two or more species, and because competition intensity increases with higher niche overlap (Schoener 1970, Hanski 1978, Hulbert 1978, Yimin et al. 2006), intra- or interspecific competitions can be estimated and compared by ecological niche overlap (Abrams 1980).

In Korea, deciduous oak species dominate in the south and central regions (Kim et al. 1981). *Q. serrata* is widespread in lowlands of the central region and the entire region of south (Chung and Lee 1965). *Q. serrata* is distributed in an optimum: warmth index of 67-92°C·month; geographic location of 35°00 to 36°30 N; and altitude of 317 m above sea level (Yim and Baek 1985, Yang 2001). *Q. serrata* is recognized as a climax species of forest succession in the south region of Korea (Park 1984, Kim and Kil 2000, Sim and Han 2003, Lee 2007, Song 2007). *Q. serrata* is mainly distributed in the south and is described as dominant tree species in cool temperate forests (Kim and Lee 2006).

Q. aliena occurs within Korean forests, in the optimum: warmth index of 67-98°C·month: with geographic location of 35°00 to 37°70 N; and altitude of 298 m above sea level (Yim and Baek 1985, Yang 2001). Contrary to *Q. serrata* which is usually the dominant overstory layer, *Q. aliena* composes the understory vegetation of secondary forests in the lowlands of the Korean Peninsula (Song 2007). This species is also an important relict vegetation of older forests and culturally important sites, such as Changdeok Palace, Secret Garden and Gongsanseong Fortress in Korea (Oh and Lee 1986) and is an instantly recognizable facet of Korean heritage.

However, *Q. serrata* and *Q. aliena* in Kwangnung Experimental Forest appeared together as a dominant species (You et al. 1995). They have been reported as potentially being the natural climax state of riverside vegetation within Korea (Kim et al. 2008a), and the edaphic climax species in moist lowland forests (Lee 2007, Song 2007). Also, Kim and Kim (1994) determined that *Q. aliena* was better able to adapt itself to moist conditions than other deciduous species. In contrast, Han et al. (2009) later reported that *Q. serrata* grew better than *Q. aliena* under conditions of flooding.

Over the past few years, only several studies based upon manipulative experiments for these two species' ecological traits. Thus, in order to understand the ecological difference and similarity between these two oak species in the natural forest, it is essential to examine each of their ecological niches, based on experimental data obtained from several controlled environment treatments (Grime et al. 1998). Linking the observed distributions of species in their native ranges to ecological niches offers a framework for predicting species distributions (Albright et al. 2010). The object of this study is to clarify these ecological characteristics in order to explain the distribution of these two oak species. Thus, we conducted growth analysis and measured ecological niche breadth and overlap between *Q. serrata* and *Q. aliena* in terms of the major environmental resources for early seedling growth.

METERIALS AND METHODS

Collecting seeds of two oak species

The seeds of both oak species were collected from the foot of a mountain at Shingwan-dong, Gongju-city, Chungnam Province, with a geographic location of 127°07′ E to 36°27′ N, and an altitude of 27 m above sea level in October of 2009. The seeds were sorted according to similarity of size, and were then stored at 4°C for approximately 6 months, until they were sown prior to the initiation of the experiment. Two acorns of each species were sown in each of 48 pots (diameter 23.5 cm, height 24 cm) filled with sterilized river bed sand in April, 2010, and the acorns germinated after 2-3 weeks.

Gradients of environmental factor

Three environmental factors, light, moisture and nutrient, were known to usually be the most important agents influencing the distribution of plants (Barbour et al. 1987). The seedlings of each species were treated with these three environmental factors, each consisting of 4 gradients. There were four replications of each treatment for each species, giving a total of 8 seedlings applied to each treatment, and an overall total of 96 seedlings.

The four gradients of the light factor treatment were as follows: L4 (high light) (100% of full light within the greenhouse, 787.75 ± 77.76 μmol $m^{-2} s^{-1}$), L3 (medium high) (50% of full light, 389 ± 45.66 μmol $m^{-2} s^{-1}$), L2 (medium low) (30% of full light, 156.2 ± 29.15 μmol $m^{-2} s^{-1}$), L1 (low light) (10% of full light, 76.8 ± 2.16 μmol $m^{-2} s^{-1}$). Light was controlled by varying the number of layers of shade cloth surrounding each treatment. Light intensity was determined with a portable LI-COR (Model 250A; Li-Cor, Lincoln, NE, USA) light meter once a day, and average values were calculated.

The four gradients of the water factor treatment were categorized as M4-M1 (mL water/plant), which was provided to the plants every 3-4 days: M4 (700 mL), M3 (500 mL), M2 (300 mL), M1 (100 mL). The reference volume of water was determined by calculating moisture carrying capacity (700 mL) of a pot, and the remaining gradients (M3-M1) were determined by reducing the volume of each by 200 mL, so as to cover a range of moisture conditions.

The nutrient treatment was also classified into four levels: N4 (15%: 127.5 mg NH_4^+-N, 82.5 mg NO_3-N), N3 (10%: 85 mg NH_4^+-N, 55 mg NO_3-N), N2 (5%: 42.5mg NH_4^+-N, 27.5mg NO_3-N), N1 (0%: none). Potting media in the nutrient experiment were fortified once only at the start of the experiment at rates of 15%, 10%, 5% and 0% fertilizer which containing an ammonium nitrogen content of below 170 mg/L, and nitrate nitrogen at a concentration of 110 mg/L (Bio-Best bed soil, Seminis) per 1 kg of sand.

Cultivation and measurements

The seedlings of *Q. serrata* and *Q. aliena* were cultivated in the glasshouse of Kongju National University from May to October 2010. Harvested seedlings were dissected and separated into shoots, roots and leaves of them with washing root part of the seedlings. We measured the petiole length, the stem length, the shoot length and the root length with a ruler in centimeter levels (cm). We also weighed the leaf weight, the petiole weight, the lamina weight, the stem weight, the shoot weight, root weight and total weight (g). The lamina length (cm), the leaf width (cm) were measured with a SKYE model SI700 plant analysis systems (SKYE, Wales, UK) and the leaf area (cm^2) were analyzed by leaf area v1.11 (Skye, 2007). Stem diameter (cm) was measured slightly above the root collar by using digital calipers (Mitutoyo, Kawasaki, Japan). All parts of the plants were dried at 70°C for 48 h before weighing.

Ecological niche breadth and ecological niche overlap

The proportional response of plants for each treatment, and along each gradient was calculated as a proportion of the sum of responses over all states (e.g., the total leaf area of each treatment was expressed as a proportion of the total leaf area for that species as the sum of all four treatments). Niche breadths were calculated for each treatment and gradient combination as follows (Levins 1968):

$$B = 1/\sum (P_i^2)\ S$$

B: niche breadth (Levins' B)

P_i: relative response of a given species to the whole gradients that is realized in gradient i

S: total number of gradients that is all treatments

Niche overlap, the equivalency of responses between two oak species was assessed by proportional similarity between pairs of two oak species. Proportional similarity (Schoener 1970) was calculated as:

$$PS = 1 - 1/2\sum |P_{ij} - P_{ih}|$$

PS = proportional similarity (niche overlap)

P_{ij} = relative response of species j in the i the gradient

P_{ih} = relative response of species h in the j the gradient

Statistical analysis

We conducted cluster analysis and principal component analysis by STATISTICA 7 (Statsoft, Inc., Tulsa, OK, USA) in order to clarify overall tendency of growth responses of both species according to environmental resource factors. The cluster analysis was used in terms of unweighted pair-group average, following estimated Euclidean distance, and principle component analysis (PCA) used spearman's correlation value of measured variables (Noh and Jeong 2002).

RESULTS

Ecological niche breadth

In niche breadth of *Q. aliena*, the characters related with leaf area, lamina length, leaf width length, petiole length, stem length, shoot length, stem diameter, root length, stem weight and shoot weight were high in the range of 0.931-1.000 in the three environmental resource treatments (Table 1). However, niche breadth of lamina weight, petiole weight, leaf weight, root weight and total weight was varied along the environmental factors; nutrient (0.958-0.993) was wider than moisture (0.691-0.985) or light (0.529-0.939). Over all, the niche breadth of *Q. ali-*

ena decreased in the order of nutrient (0.985), moisture (0.958) and light (0.913).

In niche breadth of *Q. serrata*, the characters such as leaf area, lamina length, leaf width length, petiole length, stem length, shoot length, stem diameter, root length, lamina weight, stem weight and shoot weight, were high in the range of 0.915-0.999 in all the environmental resource treatments (Table 2). But, niche breadth of petiole weight, leaf weight, root weight and total weight was varied; nutrient (0.932-0.998) was wider than moisture (0.745-0.974) or light (0.651-0.997). Average niche breadth of *Q. serrata* decreased according to nutrient (0.983), moisture (0.963) and light (0.926). As a result, light is the most important treatment because of narrower niche breadth and difference of niche breadth value between two oak species in light.

Table 1. Niche breadth of *Quercus aliena* along each environmental factor

Items	Light	Moisture	Nutrient
Leaf area	0.995	0.992	0.975
Lamina length	0.996	0.996	0.995
Leaf width length	0.998	1.000	0.992
Petiole length	0.965	0.982	0.994
Stem length	0.968	0.999	0.987
Shoot length	0.981	1.000	0.997
Stem diameter	0.971	0.947	0.984
Root length	0.984	0.989	0.989
Lamina weight	0.927	0.887	0.983
Petiole weight	0.939	0.691	0.993
Leaf weight	0.877	0.985	0.992
Stem weight	0.950	0.984	0.980
Shoot weight	0.931	0.990	0.991
Root weight	0.529	0.965	0.958
Total weight	0.681	0.971	0.970
Mean ± SD	0.913 ± 0.132	0.958 ± 0.079	0.985 ± 0.01

Table 2. Niche breadth of *Quercus serrata* along each environmental factor

Items	Light	Moisture	Nutrient
Leaf area	0.996	0.986	0.986
Lamina length	0.999	0.998	0.998
Leaf width length	0.999	0.994	0.992
Petiole length	0.985	0.990	0.985
Stem length	0.982	0.994	0.994
Shoot length	0.976	0.991	0.991
Stem diameter	0.955	0.993	0.968
Root length	0.989	0.995	0.993
Lamina weight	0.920	0.939	0.993
Petiole weight	0.997	0.745	0.998
Leaf weight	0.888	0.938	0.932
Stem weight	0.927	0.965	0.996
Shoot weight	0.915	0.967	0.973
Root weight	0.651	0.973	0.972
Total weight	0.710	0.974	0.975
Mean ± SD	0.926 ± 0.106	0.963 ± 0.063	0.983 ± 0.017

Ecological niche overlap

Ecological niche overlap between *Q. aliena* and *Q. serrata* was 0.948 for light, 0.927 for nutrient resources and 0.921 for moisture (Table 3). For light treatment, with the exception of petiole length (0.897), overlap of all characters was high 0.900-0.986. For light gradients, ecological niche overlap between two oaks was highest in the range of 0.897-0.986 among three environmental resources determined, indicating that the majority of inter-competition between the two species is based on light resources.

For nutrient treatment, leaf area (0.894) and leaf weight (0.875) were relatively narrower, while the others were relatively wider (0.904-0.973). Lamina, petiole and total weight and stem diameter were shown to have a somewhat narrower overlap (0.826-0.897) between two oak species where moisture treatment. On the other hand, the rest of the characters showed a wider overlap (0.091-

Table 3. Niche overlap between *Quercus aliena* and *Q. serrata* along each environmental factor

Items	Light	Moisture	Nutrient
Leaf area	0.975	0.960	0.894
Lamina length	0.985	0.952	0.958
Leaf width length	0.983	0.962	0.933
Petiole length	0.897	0.964	0.926
Stem length	0.953	0.947	0.973
Shoot length	0.930	0.944	0.943
Stem diameter	0.967	0.880	0.942
Root length	0.962	0.963	0.924
Lamina weight	0.986	0.881	0.916
Petiole weight	0.902	0.826	0.964
Leaf weight	0.940	0.897	0.875
Stem weight	0.900	0.936	0.922
Shoot weight	0.971	0.918	0.904
Root weight	0.903	0.901	0.905
Total weight	0.970	0.888	0.919
Mean ± SD	0.948 ± 0.034	0.921 ± 0.041	0.927 ± 0.027

0.964) (Table 3). These results mean that two oak species have also broader resource utilization in nutrient and moisture, but the extent of competition is less than light.

Cluster analysis

The environmental responses of two oak species was discriminated into two groups (Fig. 1). All the moisture and nutrient treatments, and light 3 level and 4 level of two species were clustered together in group I. Within group I, the individual oaks were again divided into two sub groups: sub-group 1 (Qal-N2 to Qal-L3), sub-group 2 (Qal-N4 to Qs-L3). Qal-N4 and -N3 belonged to group of *Q. serrata* (Qs). Group II consisted of the lower light conditions light 1 (L1) and 2 (L2) of both species. The response of the two oak species was the same to moisture level 3 (M3) and light level 4 (L4).

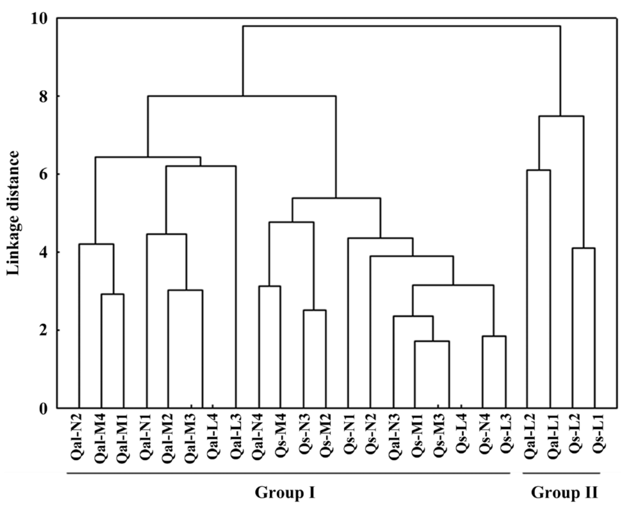

Fig. 1. Unweighted pair-group average clustering of two species treated with three environmental factors (L, light treatment; M, moisture; N, nutrient). Numerals within plot indicate treatment gradients in each environmental factor. Qal, *Quercus aliena*; Qs, *Q. serrata*.

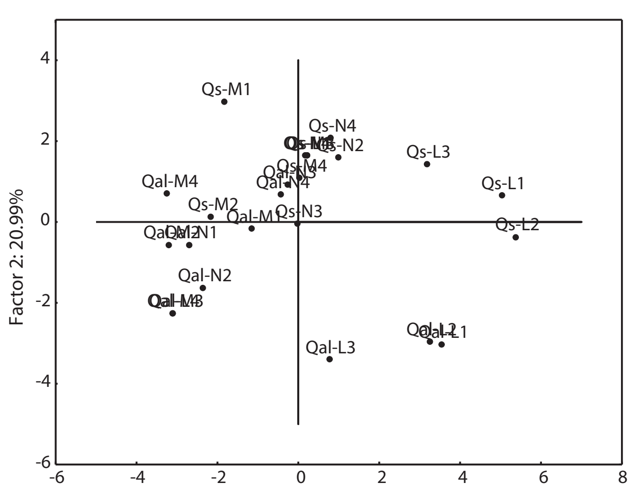

Fig. 2. Principle component analysis ordination of 24 individuals of *Quercus aliena* (Qal) and *Q. serrata* (Qs) using 15 variables treated with three environment factors (L, light treatment; M, moisture; N, nutrient). Numerals within plot indicate treatment gradients in each environmental factor.

Principal component analysis

PCA was carried out on 15 eco-morphological variables (Fig. 2). Individuals of *Q. aliena* and *Q. serrata* were plotted in the space defined by first two factor axes. Approximately, two oak species were discriminatively arranged up (Qs, *Q. serrata*) and down (Qal, *Q. aliena*) based on transversal line. Also, the configuration plot showed that nutrient (-N) and moisture (-M) requirements of both oak species were very close to each other on the left, but the light treatments (-L), especially lower light intensities (-L1, L2), were far away to the right, indicating that two oaks species have different responses to low light conditions. It is clearly visible that all features (15 variables) relied on axis 1 and axis II are highly correlated with most variables, except root length and petiole weight ($r < 0.5$) (Table 4).

Table 4. Correlation matrix of 15 variables with the first two principal component scores of principle component analysis analysis

Variables	Factor	
	I	II
Leaf area	-0.493	-0.835
Lamina length	-0.491	-0.799
Leaf width length	-0.284	-0.862
Petiole length	-0.150	-0.568
Stem length	0.734	-0.381
Shoot length	0.668	-0.488
Stem diameter	-0.743	0.129
Root length	-0.440	0.139
Lamina weight	-0.575	-0.397
Petiole weight	-0.385	0.161
Leaf weight	-0.859	0.206
Stem weight	-0.824	-0.114
Shoot weight	-0.914	0.114
Root weight	-0.859	0.190
Total weight	-0.924	0.203
Variance explained (%)	44.27	20.99

DISCUSSION

The response of the two oak species to environmental resources was related with most of the measured characters rather, and more strongly related to a few dominant one. Within the similar habitats plant species display character convergence in terms of their physiology and life history (Cody and Mooney 1978, Walter 1985). Our results of the niche breadth of two oaks species were widest where nutrient treatments were concerned and narrowest where light treatment were concerned. Therefore, where any reasonable nutrient and moisture availability exists and in generally healthy natural conditions, light is the most influential factor for the two oaks species. According to Kim et al. (2008b), niche breadth of *Q. acutissima* and *Q. variabilis* were the narrowest for light treatment. When the two species were compared (Tables 1 and 2), the niche breadth of *Q. serrata* was found to be broader than that of *Q. aliena* in terms of light and moisture resources, while both species were similar to each other in terms of nutrient resources. The broader niche breadth becomes, the more the dominance of a species increases, and similarly, a species with narrow niche breadth has a more restrictive habitat requirement (Paine et al. 1981). The results of this study indicate that *Q. serrata* has a relatively broader ecological distributions in terms of light and moisture resources than does *Q. aliena*.

In general, most early successional species have a relatively low shade tolerance and a broad ecological niche breadth in terms of light, due to their low light saturation point (Mandaák and Pyšek 2001). Also, the ecological niche breadth of early successional species is wider than that of late successional species (Lee and Bazzaz 1985). According to our study, the niche breadth of *Q. serrata* was broader than that of *Q. aliena*, and the reduction in growth of *Q. aliena* was greater than that of *Q. serrata* under shaded conditions (Ha 1989, Lim et al. 2012). Thus, we can determine that *Q. serrata* is more adapted to shade conditions than *Q. aliena*.

We found that the ecological niche overlap of the two oak species was broader in terms of light conditions than in terms of water or nutrient availability (Table 3). Thus, competition between *Q. aliena* and *Q. serrata* for light may be strong. Competition should be understood in connection with the niche concept, since some similarity or overlap in niches is a prerequisite of competition, and since niche shifts provide the clearest evidence of competition (Diamond 1978). If species have identical ecological niches, they could not avoid intraspecific and interspecific competition (Abrams 1980). The extent of niche overlap is determined by their respective resource utilization, and the extent of competition is related to the degree of overlap dimension. Each dimension in the niche space represents an environmental variable, potentially or actually important for species persistence. Species have tendencies to narrow their niches due to interspecific competition and intraspecific optimization. Consequently, niche widening often occurs when the species is released from interspecific competition (Polechová and Storch 2008). Therefore intraspecific competition is intense competition due to a broad niche overlap of their equipollency ecological niche. The two oaks species are distributed in the flood plain of natural river systems of South Korea (Kim et al. 2008a). Our result showed broader niche breadth of both species according to soil moisture and nutrient availability, and niche overlap between two species was lowest in terms of soil moisture. There is at least some competition between *Q. serrata* and *Q. aliena* though the two species can live together without competition for moisture.

Light is an important factor for early germination and seedling growth (Grime and Jeffrey 1965, Grime 1979, Canham et al. 1990, Gaudio et al. 2011, Jensen et al. 2012). Also, Hong and Nakagoshi (1998) reported that successful germination and sapling growth of oak in early successional stages is determined to a high degree by light conditions. We have discussed that *Q. serrata* is more shade tolerant than *Q. aliena*. Nonetheless, two oak species may be influenced by light due to the result of this niche overlap. This is somewhat consistent with the other experimental results. Baek and Cho (1996) found that light actually affected the growth of seedlings of *Q. serrata*. In fact, *Q. serrata* is highly dependent on light resources and is somewhat specialized in its preference for high light condition. *Q. aliena* showed an increased diameter growth compared to a further 5 deciduous oak species (*Q. acutissima*, *Q. aliena*, *Q. dentata*, *Q. mongolica*, *Q. serrata*) under 100% and 75% light treatments (Korea Forest Research Institute 1989). Also, *Q. serrata* is a representative of heliophilous trees which invade, and eventually replace grasslands in temperate regions of Japan (Yanhong et al. 1994). These results show that the factor of light clearly influenced both species which dominate this region of South Korea.

In terms of the results of cluster analysis, PCA compared well with clustering classification (Fig. 1). As Fig. 2 indicates, individuals of both oak species were found to be spatially overlapped in terms of those factors of axis I (-M and -N, L-1 and L-2) and to a lesser degree by those of axis II. The distinguishing characteristics of two oak species was related with axis II. Nutrient (-N) and moisture (-M) responses of the two oak species were closely located within the left group, and light levels (-L) except high light levels (L-3, L-4) were located on the right (Fig. 2). Based on the PCA, the ecological responses of the two oak species have similar patterns of cluster analysis (ex. Qal-N3, Qal-N4) in *Q. serrata* group I, indicating that the two oak species had an analogous response to a high nutrient conditions, and suggesting that two oak species have similar ecological responses to moisture and nutrient resources, but different responses to low light conditions. Lower light conditions of two oaks species respectively located up (Qs, L-1 and -2) and down (Qal, L-1 and -2) based on transversal line. These results determined that the spatial overlapping of the two oak species differ significantly from other deciduous oak species (Kim et al. 2008a, Lee and You 2009). The indices of niche breadth and niche overlap can be used to reflect the ecological specialization of the species within their particular environments, as well as the potential for competition with co-occurring organisms (Levins 1968). It was inferred from these data that both oak species entail the classical way to avoid or minimize competition in varying light conditions, through the differentiation of their specific light requirements.

The results of Table 4 validate the above results. The most correlation values with measured features ($r < 0.5$) means that the selected 15 variables were involved in ecological responses of both two oak species. These observations suggest that the configuration of the PCA of 24 individuals of *Q. aliena* and *Q. serrata* can be achieved either with factor I and factor II (Table 4).

Finally, both oak species have narrower ecological niche breadths and a wide ecological niche overlap in relation to light resources, and the response pattern of the two oak species to the light factor was more pronounced than that for moisture or nutrient factors. These results mean that two oak species are clearly more influenced by light resources than water or nutrient resources.

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