Interspecific and Intraspecific Variation in Pollen Grains of *Quercus* Subgenus *Lepidobalanus* Endl. in Korea

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ABSTRACT

Palynological characters such as pollen grain polar axis length (PL), pollen equatorial diameter (ED), colpus length, colpus width, and P/E ratio of six species of *Quercus* subgenus *Lepidobalanus* Endl. from Korea were studied. A significant interspecific variation, unequal distances between the species, and various degree of intraspecific variations were found. The taxonomic value of the pollen morphology parameters measured was found to vary according to species. These results suggest a possible relationship between parameters measured and ploidy level of the *Quercus* species studied.

***Key Words : Lepidobalanus*, pollen parameters, intraspecific variation, interspecific variation**

INTRODUCTION

The genus *Quercus* consists of three subgenera; *Cyclobalanopsis*, *Erythrobalanus* and *Lepidobalanus*. The fruit of *Lepidobalanus* is a nut (acorn) surrounded at base by a cup-like involucre covered outside with the appressed or spreading scales. *Lepidobalanus* is divided into the following six sections mainly on the basis of the morphology of styles and cupule: *Cerris* Loud., *Suber* Reichb., *Ilex* Loud., *Gallifera* Spach., *Robur* Reichenb. and *Prinus* Loud. (Rehder, 1940).

In Korea, six species of *Lepidobalanus* and the various hybrids resulted from their frequent interspecific hybridization are distributed throughout the Korean peninsula, and grow well. Though, in Korea, species of *Lepidobalanus* have not been considered as economic planting species and replaced by other coniferous trees, they have kept their prosperity and occupied 27% of the total stock volume in the forest where they are the dominant species with pine trees (Cho *et al.*, 1990). This suggests that species of *Lepidobalanus* play an important role in the forest ecosystem in Korea.

In Korea, species of *Lepidobalanus* grow fast and produce heavy, hard, and fine woods which have been used to make various furniture and buttresses and to decorate buildings. Also, lateral branches or small trees produced during the thinning operation have been used as an excellent host material to grow various mushrooms which are getting the spotlight as a good forest byproduct. And their cork production adds to their high value. Also, they shed parts of themselves, especially, leaves which have been excellent to fertilize the forest ground. Their fruit (acorn) which contains carbohydrate and stored protein are the important food

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for wild animals and even for Koreans who take it as a tonic (Hyun and Kang, 1993).

However, the majority of species of *Lepidobalanus* in Korea are small in diameter with low quality because of reckless deforestation and poor forest condition for a good while. So, Koreans depend on the imported logs for more than 6,735,000 m^3/year (Korea Forest Service, 2001). Therefore, it is urgently needed to increase the productivity of species of *Lepidobalanus* through their character improvement. Stands with lots of genetical variations caused by many different genes within themselves need to be selected and nurtured to improve their character (Cho, *et al.*, 1988). In Korea, species of *Lepidobalanus* occur all over the country and make various hybridization among species so they show lots of character variations. To utilize the variation as the genetical source for character improvement, the amounts and distribution types of variation need to be examined (Cho, *et al.*, 1989).

Pollen morphology can be applied to and useful for various research areas, such as taxonomy, genetic and evolutionary studies, allergy studies, melissopalynology, forensic science, tracing plant geography, geology (stratihraphy), climatic change studies, and the study of past human impact on vegetation (Kim and Song, 1998).

The pollen morphology of *Quercus* L. has been investigated by several workers (Vishnu and Singh, 1961; Smit, 1973; Lieux, 1980; Solomon, 1983a; 1983b; Medus and Flores, 1984). However, there are few studies dealing with inter- and intra-specific variation of pollen morphology traits in this genus. Olsson (1975) reported that *Quercus robur* L. and *Quercus petraea* (Mattuschka) Lieblein. showed considerable intraspecific variation in the size of pollen grain. In delimiting the subgenera *Lepidobalanus* Endl. and *Cyclobalanopsis* Prantl., Yamazaki and Takeoka (1959) and Park (1990) did not address the issue of intra- and inter-specific variation in pollen grain size and morphology.

There is little published information on factors determining intraspecific variation in pollen morphology. We hypothesize that pollen size, in *Quercus*, is influenced by the size of its nucleus, the mass of cytoplasm and its contents, and the thickness and configuration of its wall. The size of the pollen nucleus, as observed by Forlani (1953), Illies (1956), and Lifante (1996), is influenced by the set of chromosomes it contains, i.e., polyploidy level. The objectives of this study were to examine the amount of variation in morphometric traits related to pollen size among and within six widely spread Korean species of subgenus *Lepidobalanus* (genus *Quercus*), and to determine if these traits can be effectively used in the classification among these species.

MATERIALS AND METHODS

Pollen grains of the six species of subgenus *Lepidobalanus* in Korea were collected from five different populations (Fig. 1); *Q. acutissima* Carruther, *Q. aliena* Blume, *Q. dentata* Thunb. ex Murray, *Q. mongolica* Fischer ex Ledebour, *Q. serrata* Thunb. ex Murray and *Q. variabilis* Blume. Fifteen different samples per species were used, making a total of 90 samples, and the pollen grains of each sample were generally collected in the field and studied. The origin of 90 samples from five populations studied is given in Table 1, in which collection data and voucher specimens are indicated. Collected pollen grains were treated by acetolysis modified by Livingstone from Erdtman' s (Kim and Song, 1998) and mounted in glycerine jelly on microscope slides for light microscopy. Twenty randomly selected pollen grains from each of the 90 samples, 1,800 grains in total, were measured with a light microscope (BHC, Olympus Optical Co., Ltd). The parameters measured were polar axis length (PL), equatorial diameter (ED), colpus

Table 1. *Lepidobalanus* samples investigated.

Taxon	Source and voucher	Chromosome number (2*n*)[a]
Q. acutissima[b]	Mt. Gwanak, Gyeonggi Prov., S. Kim 1009	24
	Mt. Gwanak, Gyeonggi Prov., S. Kim 1211	
	Mt. Gwanak, Gyeonggi Prov., S. Kim et al. 1013	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1379	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1284	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1950	
	Mt. Mudeung, Gwangju, K. H. Kim & S. Kim 1436	
	Mt. Mudeung, Gwangju, K. H. Kim & S. Kim 1228	
	Mt. Mudeung, Gwangju, K. H. Kim & S. Kim 1117	
	Mt. Seorak, Gangwon Prov., S. Kim 1290	
	Mt. Seorak, Gangwon Prov., S. Kim *et al.* 1006	
	Mt. Seorak, Gangwon Prov., S. Kim 1030	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1105	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1084	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1787	
Q. aliena[c]	Mt. Gwanak, Gyeonggi Prov., K. H. Kim & S. Kim 0920	?
	Mt. Gwanak, Gyeonggi Prov., S. Kim 1448	
	Mt. Gwanak, Gyeonggi Prov., S. Kim *et al.* 1501	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1711	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1059	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1739	
	Mt. Mudeung, Gwangju, K. H. Kim & S. Kim 1311	
	Mt. Mudeung, Gwangju, K. H. Kim & S. Kim 1112	
	Mt. Mudeung, Gwangju, S. Kim et al. 1900	
	Mt. Seorak, Gangwon Prov., S. Kim 1240	
	Mt. Seorak, Gangwon Prov., S. Kim et al. 1295	
	Mt. Seorak, Gangwon Prov., S. Kim 1821	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1008	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1224	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1248	
Q. dentata[c]	Mt. Gwanak, Gyeonggi Prov., K. H. Kim & S. Kim 1223	24, 48
	Mt. Gwanak, Gyeonggi Prov., S. Kim 1352	
	Mt. Gwanak, Gyeonggi Prov., S. Kim et al. 1925	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1776	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1256	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1461	
	Mt. Mudeung, Gwangju, K. H. Kim & S. Kim 1622	
	Mt. Mudeung, Gwangju, K. H. Kim & S. Kim 1333	
	Mt. Mudeung, Gwangju, S. Kim 1497	
	Mt. Seorak, Gangwon Prov., S. Kim 1515	
	Mt. Seorak, Gangwon Prov., S. Kim 0983	
	Mt. Seorak, Gangwon Prov., S. Kim et al. 0984	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1969	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1929	
	Mt. Palgong, Gyeongbuk Prov., S. Kim *et al.* 1938	

Q. mongolica[c]	Mt. Gwanak, Gyeonggi Prov., K. H. Kim & S. Kim 1968	24
	Mt. Gwanak, Gyeonggi Prov., S. Kim 1971	
	Mt. Gwanak, Gyeonggi Prov., S. Kim et al. 1973	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1975	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1020	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1018	
	Mt. Mudeung, Gwangju, S. Kim *et al.* 1888	
	Mt. Mudeung, Gwangju, S. Kim *et al.* 1131	
	Mt. Mudeung, Gwangju, S. Kim *et al.* 1276	
	Mt. Seorak, Gangwon Prov., S. Kim *et al.* 1500	
	Mt. Seorak, Gangwon Prov., K. H. Kim & S. Kim 1005	
	Mt. Seorak, Gangwon Prov., K. H. Kim & S. Kim 1430	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1213	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1725	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1119	
Q. serrata[c]	Mt. Gwanak, Gyeonggi Prov., K. H. Kim & S. Kim 1325	24
	Mt. Gwanak, Gyeonggi Prov., S. Kim 1720	
	Mt. Gwanak, Gyeonggi Prov., S. Kim 1886	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1516	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1534	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1061	
	Mt. Mudeung, Gwangju, K. H. Kim & S. Kim 1918	
	Mt. Mudeung, Gwangju, K. H. Kim & S. Kim 1006	
	Mt. Mudeung, Gwangju, K. H. Kim & S. Kim 1296	
	Mt. Seorak, Gangwon Prov., K. H. Kim & S. Kim 1283	
	Mt. Seorak, Gangwon Prov., S. Kim *et al.* 1622	
	Mt. Seorak, Gangwon Prov., S. Kim *et al.* 1328	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1727	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1828	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1621	
Q. variabilis[b]	Mt. Gwanak, Gyeonggi Prov., K. H. Kim & S. Kim 1428	24
	Mt. Gwanak, Gyeonggi Prov., K. H. Kim & S. Kim 1323	
	Mt. Gwanak, Gyeonggi Prov., S. Kim 1342	
	Mt. Gyeryong, Chungnam Prov., S. Kim *et al.* 1539	
	Mt. Gyeryong, Chungnam Prov., S. Kim *et al.* 1608	
	Mt. Gyeryong, Chungnam Prov., S. Kim 1220	
	Mt. Mudeung, Gwangju, K. H. Kim & S. Kim 1082	
	Mt. Mudeung, Gwangju, S. Kim 1225	
	Mt. Mudeung, Gwangju, S. Kim 1232	
	Mt. Seorak, Gangwon Prov., K. H. Kim & S. Kim 1075	
	Mt. Seorak, Gangwon Prov., K. H. Kim & S. Kim 1725	
	Mt. Seorak, Gangwon Prov., S. Kim *et al.* 1324	
	Mt. Palgong, Gyeongbuk Prov., S. Kim 1622	
	Mt. Palgong, Gyeongbuk Prov., S. Kim *et al.* 1753	
	Mt. Palgong, Gyeongbuk Prov., S. Kim *et al.* 1325	

[a]Fedrov, 1969 and Wang, 1986.
[b]Section *Cerris* Loud.
[c]Section *Prinus* Loud.
The voucher specimens are deposited at the herbarium of Faculty of Forest Science, Chonbuk National University.

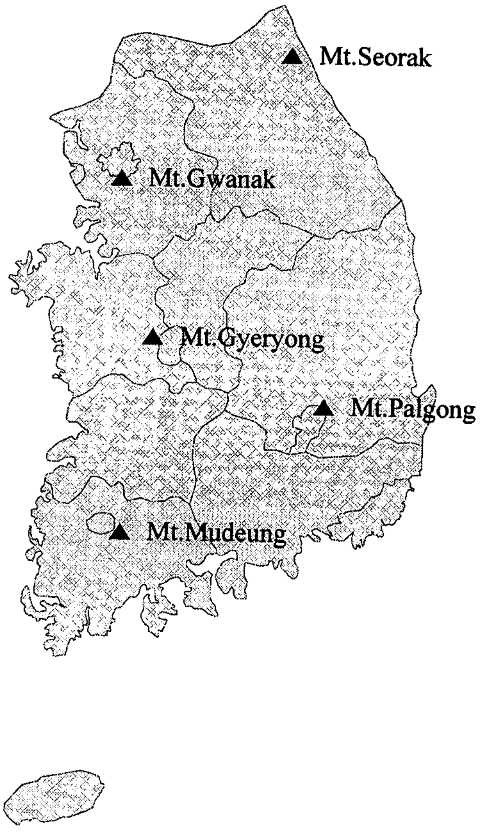

Fig. 1. Map showing the sampling sites of five populations of subgen. *Lepidobalanus* in Korea.

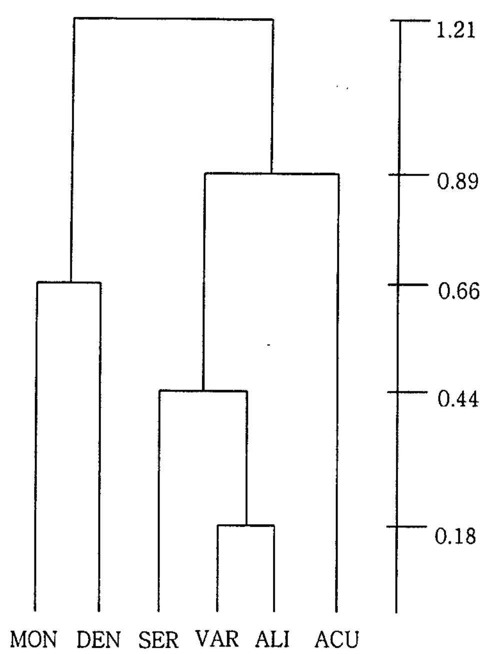

Fig. 2. Average linkage cluster phenogram presenting the relationship among six species of subgenus *Lepidobalanus* in Korea based on Mahalanobis distances from five pollen morphological traits.
Note: See Table 3 for abbreviations.

length (CL), and colpus width (CW), and P/E (PL/ED) ratio was calculated. The terminology of pollen morphology used here follows that of Erdtman (1969) and Praglowski and Raj (1979).

The hypothesis of equal group (species) centroids was tested by multiple analysis of variance (MANOVA). Following this procedure, individuals were classified to species based on the pollen parameters, using discriminant analysis. To better describe the interrelationships among species according to the pollen parameters, Mahalanobis distances were calculated. All statistical procedures were carried out using SAS version 6.12 (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Variation among species

The pollen morphological data for the six species studied are summarized in Table 2. *Quercus dentata* showed the largest mean values in pollen grain size parameters measured, whereas *Q. serrata* showed the smallest mean values. The hypothesis of no difference among species with respect to the five pollen parameters including P/E (PL/ED) value was tested by MANOVA. The analysis yielded a Wilks' λ of 0.284 with an F value of 90.84 (the probability of a greater F was 0.0001), suggesting that the hypothesis of no differences among species could not be accepted.

The increase of cell volume and all parts of a plant as a consequence of an increase in ploidy level is a well-established fact (Stebbins, 1950; Davis and Heywood,

Table 2. Pollen morphological data: polar axis length (PL), equatorial diameter (ED), colpus length (CL), colpus width (CW), and polar axis length/equatorial diameter (P/E); the range is given in parentheses.

Taxon	Pollen grain size(μm)		Colpus(μm)		P/E
	PL	ED	CL	CW	
Q. acutissima					
Mt. Gwanak	27.3(22-33)	26.8(19-30)	21.6(13-28)	1.7(1.5-2.2)	1.02(0.90-1.32)
Mt. Gyeryong	29.6(26-34)	29.5(26-34)	23.2(20-28)	1.6(1.5-2.2)	1.01(0.88-1.21)
Mt. Mudeung	28.4(23-32)	26.3(22-31)	22.6(19-27)	1.8(1.5-2.2)	1.09(0.95-1.32)
Mt. Palgong	26.5(22-35)	26.2(20-31)	21.0(16-27)	1.8(1.5-2.6)	1.01(0.86-1.44)
Mt. Seorak	27.8(23-32)	27.4(22-31)	22.1(17-26)	1.6(1.5-2.2)	1.02(0.88-1.23)
Mean(SE)	27.8(0.17)	27.2(0.16)	22.0(0.16)	1.7(0.02)	1.03(0.006)
Q. aliena					
Mt. Gwanak	25.5(21-32)	24.7(20-30)	20.3(15-27)	1.5(1.1-1.9)	1.04(0.88-1.38)
Mt. Gyeryong	26.2(23-32)	25.7(22-32)	20.2(17-26)	1.6(1.5-2.2)	1.02(0.86-1.13)
Mt. Mudeung	26.1(22-32)	23.5(19-28)	19.5(14-27)	1.6(1.1-2.2)	1.12(0.85-1.45)
Mt. Palgong	24.7(22-31)	24.3(18-28)	19.6(16-24)	1.5(1.5-2.2)	1.03(0.80-1.40)
Mt. Seorak	24.5(19-32)	23.6(19-26)	19.2(13-26)	1.5(1.5-1.9)	1.04(0.89-1.39)
Mean(SE)	25.4(0.15)	24.3(0.13)	19.8(0.15)	1.5(0.01)	1.05(0.007)
Q. dentata					
Mt. Gwanak	29.6(20-35)	26.3(19-33)	22.0(17-27)	1.5(1.1-1.9)	1.13(0.89-1.29)
Mt. Gyeryong	33.0(27-39)	29.5(25-33)	23.9(20-30)	1.6(1.5-3.0)	1.12(0.96-1.32)
Mt. Mudeung	32.0(23-38)	29.3(23-34)	25.0(18-33)	1.7(1.5-2.6)	1.09(0.93-1.28)
Mt. Palgong	31.5(23-34)	28.5(21-32)	23.8(18-28)	1.5(1.1-1.9)	1.11(0.95-1.36)
Mt. Seorak	31.7(26-37)	27.6(24-31)	23.2(20-29)	1.6(1.1-1.9)	1.15(0.96-1.33)
Mean(SE)	31.6(0.21)	28.3(0.17)	23.6(0.19)	1.6(0.01)	1.12(0.006)
Q. mongolica					
Mt. Gwanak	29.3(24-35)	24.5(21-30)	21.4(16-25)	1.4(1.1-1.9)	1.20(0.99-1.44)
Mt. Gyeryong	28.4(23-32)	24.7(19-29)	22.9(19-26)	1.7(1.5-2.2)	1.16(0.94-1.42)
Mt. Mudeung	31.6(26-36)	26.2(18-30)	24.0(18-29)	1.4(1.1-1.9)	1.21(1.05-1.56)
Mt. Palgong	30.3(24-36)	25.1(22-27)	24.0(18-29)	1.5(1.1-1.9)	1.21(0.98-1.47)
Mt. Seorak	30.9(24-35)	24.9(22-30)	23.5(15-26)	1.4(1.1-1.9)	1.24(1.06-1.45)
Mean(SE)	30.2(0.16)	25.1(0.12)	23.2(0.15)	1.5(0.01)	1.21(0.007)
Q. serrata					
Mt. Gwanak	25.7(23-28)	22.8(20-30)	19.8(17-23)	1.6(1.5-1.9)	1.14(0.78-1.35)
Mt. Gyeryong	24.7(17-32)	21.7(17-26)	19.5(15-26)	1.6(1.5-1.9)	1.14(0.93-1.42)
Mt. Mudeung	26.6(23-30)	21.9(19-28)	20.1(17-23)	1.5(1.1-1.9)	1.22(1.06-1.38)
Mt. Palgong	24.8(20-28)	23.1(19-29)	19.5(16-26)	1.5(1.1-1.9)	1.08(0.91-1.39)
Mt. Seorak	23.7(20-27)	22.3(19-26)	18.8(16-21)	1.5(1.5-1.9)	1.07(0.86-1.28)
Mean(SE)	25.1(0.13)	22.3(0.14)	19.5(0.12)	1.5(0.01)	1.13(0.007)
Q. variabilis					
Mt. Gwanak	27.7(24-33)	25.5(22-29)	20.2(17-26)	1.5(1.1-1.9)	1.09(1.00-1.28)
Mt. Gyeryong	28.5(24-33)	25.7(21-30)	22.6(18-28)	1.6(1.5-1.9)	1.11(0.96-1.44)
Mt. Mudeung	25.7(18-34)	23.5(19-29)	20.0(14-28)	1.5(1.1-2.2)	1.09(0.87-1.42)
Mt. Palgong	27.8(26-32)	26.6(24-31)	20.8(18-24)	1.6(1.5-2.2)	1.05(0.92-1.22)
Mt. Seorak	27.5(24-30)	25.9(21-30)	21.0(17-25)	1.5(1.1-1.9)	1.06(0.95-1.32)
Mean(SE)	27.6(0.15)	25.6(0.13)	21.0(0.15)	1.5(0.01)	1.08(0.005)

Table 3. Squared Mahalanobis distances between six species of subgenus *Lepidobalanus* in Korea based on five pollen parameters.

Species	ACU	ALI	DEN	MON	SER	VAR
ACU	0.0					
ALI	2.93850	0.0				
DEN	3.60495	6.57005	0.0			
MON	5.37840	3.98188	2.85545	0.0		
SER	5.65855	1.11153	9.67771	4.12847	0.0	
VAR	2.10010	0.80382	2.88920	1.91492	2.50804	0 .0

Note: ACU, *Q. acutissima*; ALI, *Q. aliena*; DEN, *Q. dentata*; MON, *Q. mongolica*; SER, *Q. serrata*; VAR, *Q. variabilis.*

Table 4. Pearson correlation coefficients (*R*) between four pollen parameters in six species of subgenus *Lepidobalanus* in Korea.

	PL	ED	CL	CW
PL				
P>*R*	0.0			
ED	0.62240			
P>*R*	0.0001	0.0		
CL	0.81850	0.53830		
P>*R*	0.0	0.0001	0.0	
CW	-0.01589	0.08578	-0.00219	
P>*R*	0.5317	0.0007	0.9312	0.0

Note: PL, polar axis length; ED, equatorial diameter; CL, colpus length; CW, colpus width.

1963; Lewis, 1980). Variation in pollen characters related to the changes in ploidy level has been indicated for different plant groups by several authors (Pastor, 1981; Keenan, 1982; Sagoo and Bir, 1983; Romero and Blanca, 1985; Fernandes, 1990; Kim *et al.*, 1990). Nevertheless, in many cases, there is no variation in pollen characters related to polyploidy. However, the species showing the largest values in pollen parameters in this study is observed to be tetraploid (or diploid) (Fedrov, 1969; Wang, 1986). We hypothesize, therefore, that the pollen parameters measured are closely related to chromosome numbers in subgenus *Lepidobalanus* in Korea.

Table 3 shows the Mahalanobis distances among the species based on the five variables measured. This calculation demonstrates that the largest distance is between *Q. dentata*, tetraploid (or diploid), and *Q. serrata*, diploid, (9.67771) and the smallest distance, between *Q. aliena* and *Q. variabilis* (0.80382). A phenogram (Fig. 2), produced based on the Mahalanobis distances, showed the relationship among six species in this study.

Correlation of pollen morphology parameters

Table 4 shows the Pearson correlation coefficients between the four measured pollen parameters. A highly significant positive correlation was found between CL and PL, and between PL and ED, suggesting that colpus length (CL) and equatorial diameter (ED) were associated with polar axis length (PL). It is interesting, however, that CW was not correlated with either PL, ED, or CL, suggesting that colpus width was independent from CL, PL, and ED (Table 4).

Variation within each species

The hypothesis of no differences among populations

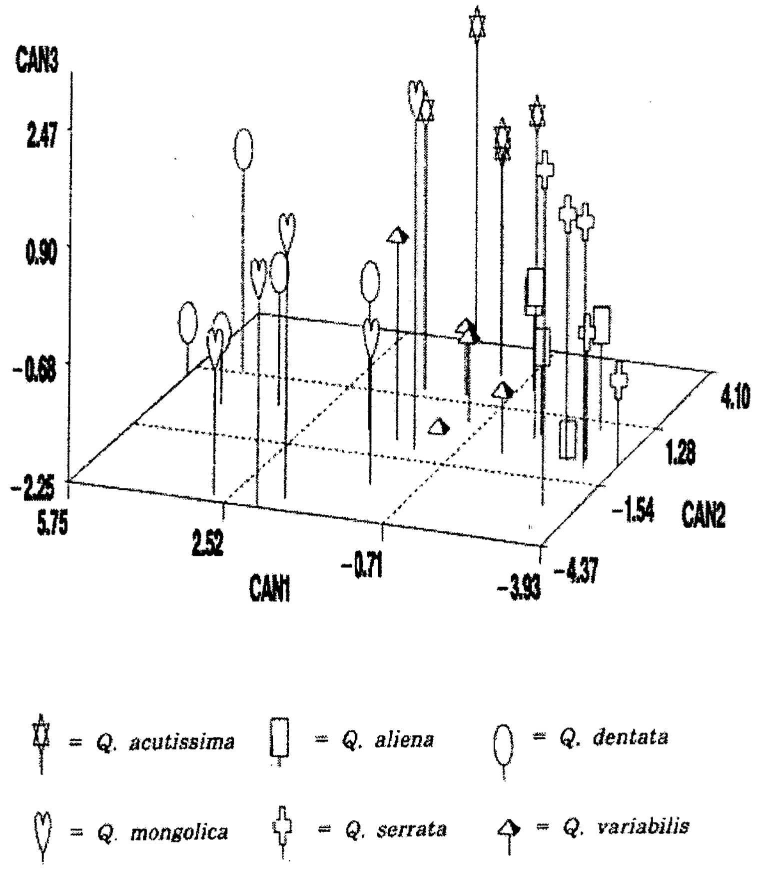

Fig. 3. Distribution of five populations of subgenus *Lepidobalanus* in Korea based on the canonical analysis of variances for the five pollen morphology characteristics measured.

within species was tested by MANOVA. The analysis yielded a Wilks' λ of 0.625 with an F value of 7.50 (P=0.0001), which suggests that the hypothesis of no difference must be rejected. The six species studied showed different degrees of intraspecific variation in pollen parameters measured (Table 2). The values for standard error, indicating such variation, were much higher for *Q. dentata* than for the other five species studied.

The results of a canonical analysis (Fig. 3) illustrate further the intraspecific variation in the six species studied. *Quercus serrata* and *Q. aliena* form tight distinctive clusters, in which only one of the populations in each species is more differentiated, and only along the 2nd and 3rd axes (*Q. serrata*) or the 3rd axis (*Q. aliena*). *Quercus mongolica* varies more widely, especially along the 3rd canonical axis, and *Q. dentata* varies very widely along the 1st and 3rd canonical axes.

There was a larger degree of within-species variation observed in PL, CL and ED than in CW. The reason for this difference in variation of the different parameters measured is not apparent, especially with the lack of correlation of CW with other parameters and the strong correlation found between PL and CL, PL and ED, and CL and ED. Large intraspecific variation in PL of pollen grains was also observed in the study of Križo (1980) in *Salix*. However, the reason for this variation

Table 5. Classification of species on the basis of pollen parameters measured (discriminant analysis of PL, ED, CL, CW, and P/E ratio).

Species	ACU	ALI	DEN	MON	SER	VAR	Total
ACU							
No. of grain	187	30	32	15	18	18	300
% of total	62.33	10.00	10.67	5.00	6.00	6.00	100.00
ALI							
No. of grain	22	186	4	22	45	21	300
% of total	7.33	62.00	1.33	7.33	15.00	7.00	100.00
DEN							
No. of grain	44	8	200	17	14	17	300
% of total	14.67	2.67	66.67	5.67	4.67	5.67	100.00
MON							
No. of grain	21	11	19	194	24	31	300
% of total	7.00	3.67	6.33	64.67	8.00	10.33	100.00
SER							
No. of grain	11	78	1	11	190	9	300
% of total	3.67	26.00	0.33	3.67	63.33	3.00	100.00
VAR							
No. of grain	33	36	21	29	21	160	300
% of total	11.00	12.00	7.00	9.67	7.00	53.33	100.00
Total	318	349	277	288	312	256	1800
Percent	17.67	19.39	15.39	16.00	17.33	14.22	100.00

Note: See Table 2 and 3 for abbreviations.

was neither analyzed nor hypothesized by the author.

Various degrees of intraspecific variation in measured pollen parameters could reflect the genetic variation in the species. We can also hypothesize about environmental effects, such as temperature and drought, causing such variation. While we can only speculate on such effects, it has been observed in taxa other than *Quercus* that variation in chromosome numbers (and ploidy levels) was related to the size of pollen grains (Forlani, 1953; Illies, 1956; Lifante, 1996). In *Quercus*, there are several examples of polyploidy not only between species, but also within species (Fedrov, 1969; Wang, 1986). Similarly, the occurrence of different ploidy levels within species was recorded for *Q. dentata* by Fedrov (1969). Our results suggest that the larger degree of variation in pollen parameters (especially PL, ED, and CL) for *Q. dentata*, as compared with the other five species studied, was due to the existence of polyploid (and probably aneuploid) types in *Q. dentata*.

Taxonomic value of pollen

The taxonomic value of pollen was analyzed on the basis of the pollen grain parameters measured, using a discriminant analysis that assigned each experimental unit (pollen grain) to the species. The results of this classification are shown in Table 5. Accordingly, 62% of the *Q. aliena* pollen grains were correctly classified as *Q. aliena* and 15% were incorrectly classified as *Q. serrata* while 67% of the *Q. dentata* pollen grains were correctly classified as *Q. dentata* and 15% were incorrectly classified as *Q. acutissima*. For *Q. serrata*, 63% of pollen grains were correctly classified as *Q. serrata* and 26% were incorrectly classified as *Q. aliena*. Especially, less than 1% of the *Q. serrata* pollen grains were classified as *Q. dentata*. Only 53% of the *Q. variabilis* pollen grains were correctly classified, and the rest were incorrectly classified. Thus, the taxonomic value of pollen morphology parameters measured varied species to species.

Values from Table 3 and 5 show a correlation. For instance, there were few misclassified pollen grains between *Q. dentata* and *Q. serrata* (Table 5) and the squared distance between these two species was the largest (9.67771; Table 3). *Quercus aliena* and *Q. variabilis*, which were the most closely associated (Table 3), were also misclassified for each other in most of the cases (Table 5).

CONCLUSIONS

This study has shown significant interspecific variation in pollen grain axis length (PL), pollen equatorial diameter (ED), colpus length (CL), colpus width (CW), and P/E (PL/ED) ratio. However, the species distances in these parameters were unequal. The species showing the largest values in pollen parameters in this study was observed to be tetraploid (or diploid). In subgenus *Lepidobalanus*, pollen size has proved to be of little use at the interspecific level, since there is a clear overlapping of values for the different species. The taxonomic value of the pollen parameters in species recognition was lower in other cases (Lee and Park, 1980; Kim *et al.*, 1990).

The intraspecific variation in the pollen parameters measured was significant, in general, but varied with species. Two of the six species studied showed tight clustering, while *Quercus dentata* showed wide variation. These results suggest a possible relationship between parameters measured and ploidy level of the *Quercus* species studied.

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