

A morphometric analysis of the eastern Asian *Kalopanax septemlobus* (Thunb.) Koidz. (Araliaceae)

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Abstract. *Kalopanax septemlobus* (Thunb.) Koidz., a woody species of Araliaceae, exhibits a broad range of morphological variation and occurs throughout much of eastern Asia. A morphometric analysis of herbarium material supplemented with a large sample of field-collected leaves was undertaken to determine if the morphological differentiation found within *Kalopanax septemlobus* warranted the taxonomic recognition of distinct taxa. One hundred twenty six individuals representing the total geographic range of the species were scored for 20 morphological characters, and the data matrix was subjected to principal components analysis. The results indicated that *Kalopanax septemlobus* should be recognized as one polymorphic species. Previously recognized infraspecific taxa were not supported to warrant the designation of any taxonomic rank. The observed pattern of variation may be environmentally induced and suggests that the species may exhibit environmental plasticity.

Keywords: Araliaceae; Forms; *Kalopanax septemlobus*; *Kalopanax septemlobus* subsp. *lutchuensis*; Morphometrics; Principal components analysis.

Introduction

Castor Aralia, *Kalopanax septemlobus* (Thunb.) Koidz. (Araliaceae), is a well-defined species native to eastern Asia, Japan, Korea, China, and eastern coastal Russia (Willis, 1973) (Figure 1). Recent phylogenetic studies of the nuclear ribosomal DNA internal transcribed spacer (ITS) of Araliaceae have supported the monophyly of *Kalopanax* and *Eleutherococcus* and their placement in a broad assemblage comprising taxa largely with compound leaves (Wen et al., 2001).

Within the species, morphological variation is exhibited at many levels, from within a single population to among local and regional entities. Taxonomic treatments of this differentiation by previous workers (Nakai, 1927; Rehder, 1947; Lee, 1980; Hara, 1986) have recognized various numbers of infraspecific taxa at either the varietal or subspecific rank, usually based on minor differences in leaf morphology and trichoms which has made identification difficult. Zabel (in Ohashi, 1994) first noted that some of *K. septemlobus* was distinguished by tufted hairs on the basal axil of the main nerves, which he recognized as var. *magnificus*. Similarly, Van Houtte (1874) and Nakai (1927)

attempted to describe specimens with deeply incised leaves, which they designated as var. *maximowiczii*. However, Hara (1954) presented arguments favoring recognition of Nakai's variety as a form. Authors of regional flora treatments (Lee, 1980; Hoo and Tseng, 1978) have agreed with Nakai and Zabel's circumscriptions for the most part, maintaining the taxa at the varietal level. On the other hand, neither var. *maximowiczii* nor var. *magnificus* were

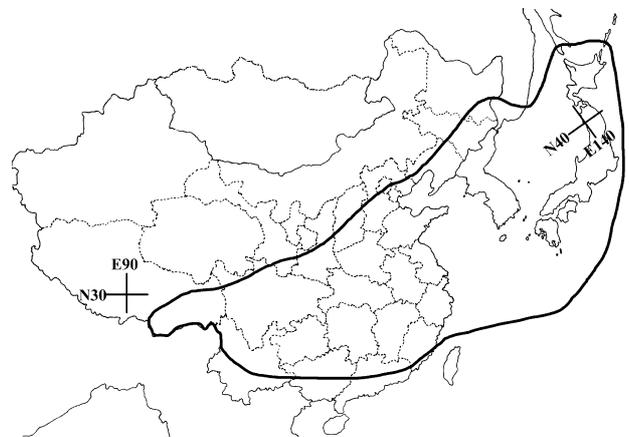


Figure 1. Maximum extent of geographic distribution of *Kalopanax septemlobus* in eastern Asia.

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recognized in recent floras of Russia and Japan (Kitamura and Murata, 1984; Charkevicz, 1987). Likewise, Ohwi (1984) did not accept these two varieties in his flora, but he did recognize var. *lutchuensis* as the southern glabrous type.

There is a clear need for a comprehensive study of this complex that goes beyond the limited work done previously as a small part of a major floristic endeavor thus far. Two major treatments of this complex (Kitamura and Murata, 1984; Charkevicz, 1987 vs. Ohwi, 1984) differed from each other primarily in the importance given to the presence of pubescence and shallowly to deeply lobed leaves. In a recent review, Ohashi (1994) clarified the nomenclature of *Kalopanax septemlobus*, and proposed two subspecies, including several forms based only on an analysis of Japanese individuals: *K. septemlobus* subsp. *septemlobus* for. *septemlobus*, and for. *maximowiczii* (Van Houtte) H. Ohashi; and subsp. *lutchuensis* (Nakai) H. Ohashi. Ohashi (1994) differed from Van Houtte (1874) and Nakai (1927) in considering var. *magnificus* to represent the same taxon as var. *maximowiczii*. Also, Ohashi (1994) regarded the previously recognized var. *maximowiczii* as a highly variable entity with no apparent morphological characteristics to distinguish it from typical material, which led him to reduce it to a form under *K. septemlobus* subsp. *septemlobus*. The presence of scarce tufted hairs on the basal axil of the main nerves is characteristic of material assigned to for. *septemlobus*. These hairs are dense in for. *maximowiczii* and absent altogether in subsp. *lutchuensis*. Leaves of var. *lutchuensis* are usually (3-)5-lobed, thick, and lustrous on the upper surfaces while those of the other taxa are usually 5-7-lobed, relatively thin, and not lustrous. Ohashi (1994) also considered that deeply incised leaves are found in *K. septemlobus* subsp. *septemlobus* for. *septemlobus* and *K. septemlobus* subsp. *septemlobus* for. *maximowiczii*, but not in subsp. *lutchuensis*.

The purpose of this paper is to analyze the phenetic relationships among the different morphological entities of *Kalopanax septemlobus* from throughout eastern Asia. Particular attention has been given to determining if the morphological variation among the previously distinguished taxa warrants recognition at the rank of species. For this we have used a large sample of field-collected leaves and comparative methods of quantitative characters to examine patterns of geographical distribution. The level of polymorphism on leaf shape and size was evaluated

within several testable populations to assess the constancy of these characters.

Materials and Methods

Herbarium specimens were selected to represent the entire geographical range of *Kalopanax septemlobus* complex and to reflect the morphological variability present in the species. Material were borrowed from various herbaria including CNU (Chunnam National University, not listed in Index Herbariorum), PE, SNU, SNUA, and TUS (Holmgren et al., 1990). Additionally data were obtained from pressed specimens collected in the summer and over a four-year period (1998 to 2001) from several populations in South Korea and northern Japan. Voucher specimens were on deposit at SNUA.

Twenty morphological characters (Table 1) were selected for analyses, included those most frequently utilized in keys and diagnoses to distinguish taxa within *Kalopanax*. Inflorescence and flower features were not measured because these were not previously used for infraspecific delimitation. Measurements were taken with a hand ruler and an ocular micrometer. Illustration of the leaf morphologies was done by drawing the traced outlines of photocopied herbarium specimens (Figure 2).

The OTUs were grouped both geographically and based on *a priori* identification to varieties (52 specimens from China, 14 from the main islands of Japan, one from Okinawa of Japan, 59 from Korea, and four from Russia) (Appendix). All specimens used in the analyses were at their mature stage of development. In most cases, only one mature leaf per plant was used to represent an individual. In order to assess morphological variation within and among individuals, eighty leaves from one individual tree examined in the field were measured for our initial examination.

Morphological variation was assessed using univariate statistics (mean, maximum, minimum) and multivariate analysis (PCA). Univariate analyses were performed using the SAS-PC package (version 6.04) developed by SAS Institute (1988). For each geographic group and the individual tree examined, descriptive statistics and character correlation were calculated and normality tests were performed. Samples departing from normality were either log or square-root transformed. One-way analysis of variance, using geographic group as a treatment, was performed on each

Table 1. Characters used in morphological analysis of *Kalopanax septemlobus*.

1. Number of leaf lobes	11. Width of second left lobe
2. Angle (three major lobe)	12. Width of first right lobe
3. Leaf width	13. Width of second right lobe
4. Petiole length	14. Length of first left lobe
5. Depth of first left lobe	15. Length of second left lobe
6. Depth of first right lobe	16. Length of first right lobe
7. Leaf length	17. Length of second right lobe
8. Number of trichomes per 3 mm ² , measured beneath main vein	18. Ratio (length/width)
9. Width of central lobe	19. Ratio (leaf length/petiole length)
10. Width of first left lobe	20. Ratio (depth of first left lobe/leaf length)

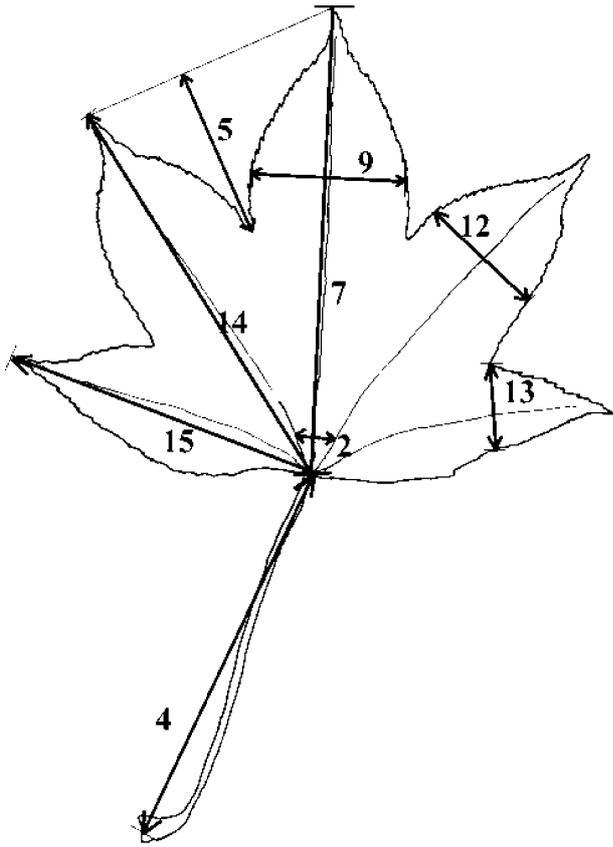


Figure 2. Diagram of leaf characters measured for numerical analysis. Numbers correspond to character number in Table 1.

character that could be normalized ($P \leq 0.05$). A one-way Kruskal-Wallis test was performed for all non-normal samples.

Principal components analysis (PCA) was performed using the SAS-PC package. PCA was conducted on the matrix of product-moment correlations, obtained from the standardized data, to provide further insight into structure in the data set. This method is well-suited to revealing patterns of continuous variations in a data set (Sneath and Sokal, 1973). Specimens were projected onto the eigenvectors, and *a priori* assignment to varieties was also plotted in two dimensions for examination.

Results

The results of the univariate analysis were shown in Figure 3, along with the minimum and maximum values for some important characters. Some features traditionally used to differentiate the varieties of *Kalopanax septemlobus* showed patterns of variation that were inconsistent with the descriptions of the subspecies (Ohashi, 1994). The character of ratio (length/width) to depth of leaf lobe generally used to differentiate subsp. *lutchuensis*, was common in Korea, northern China and Japan. Analysis of the distribution of these traits indicated that plants in several parts of southern China consistently possessed

fewer lobes than material assigned to subsp. *septemlobus*. Glabrous to subglabrous leaves, a trait also associated with var. *septemlobus*, were frequent but not fixed in any of the regions. No discrete regional groups could be defined by any single measure (Figure 3). Although OTUs from China overlapped with individuals from Korea and Japan, southern Chinese individuals and those from Okinawa shared a close morphological similarity.

In the principal components analysis, the scores of the first three components accounted for 53.70%, 13.84%, and 7.26% of the total variance, respectively, or 74.80% altogether. Ordination of principal components 1 vs. 2 (Figure 4A) revealed clusters of OTUs that did not corresponded to geographic groups. In both plots, several OTUs obtained from an individual tree occupied the central area of the plot and overlapped with OTUs from all geographic groups. The majority of the material from Korea was represented the remainder of the OTUs along the second principal component axis, and some individuals

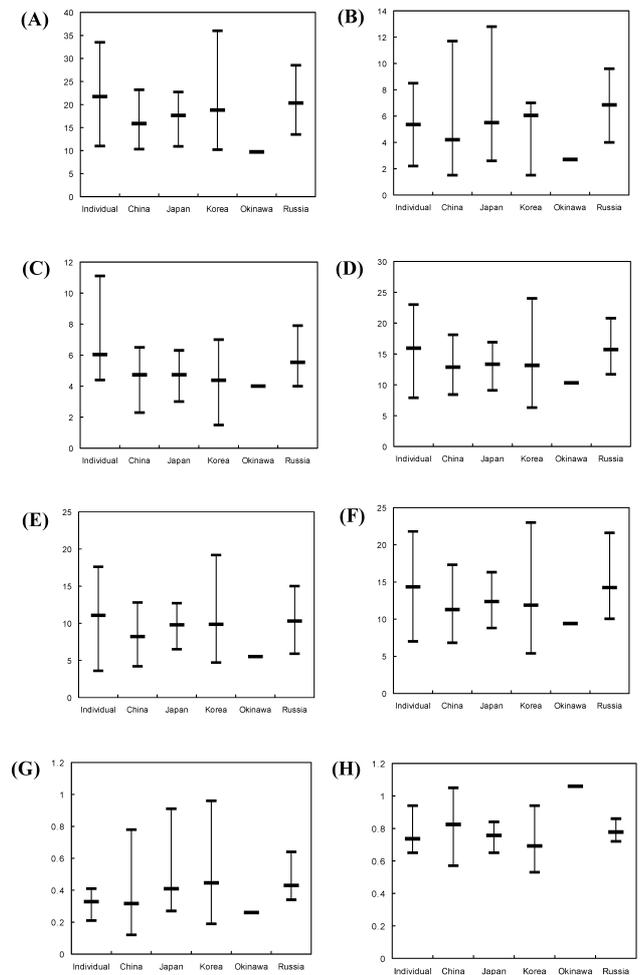
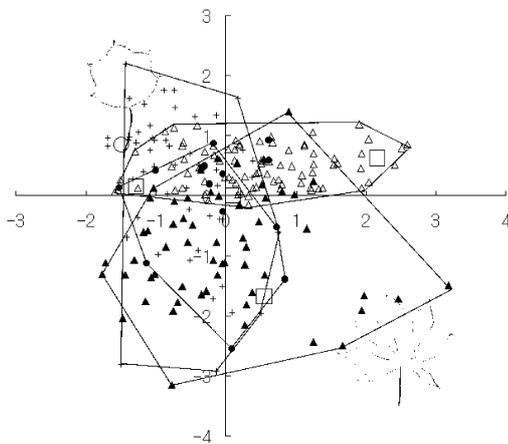


Figure 3. Mean and range of values for characters used to differentiate taxa in *Kalopanax septemlobus*. (A) leaf width; (B) depth of first left lobe; (C) leaf length; (D) width of central lobe; (E) length of first right lobe; (F) length of first left lobe; (G) ratio (leaf length/width); (H) ratio (depth of lobe / leaf length).

from China clustered at the other end of this axis together with the individual from Okinawa at the upper left side of the first axis. It should also be noted that leaves from individual trees were grouped in the center of the axis and spread along first axis. Some samples from the western part of Korea, i.e., the island Deokjeok-do (a coastal type) and from parts of China (Szechuan, Guangdong, Guangxi, Yunnan, Guizhou) were somewhat distinct although their distribution in the PCA overlapped with other clusters of OTUs toward the center of the projection. The small, but relatively shallowly dissected, leaves from southern China would be distinguished from the more dissected leaves of the other populations. The second component corresponded primarily to shape, relative incision size between lobe, and the lengths of the second left and right lobes. However, the specimens with these characters showed a

(A)



(B)

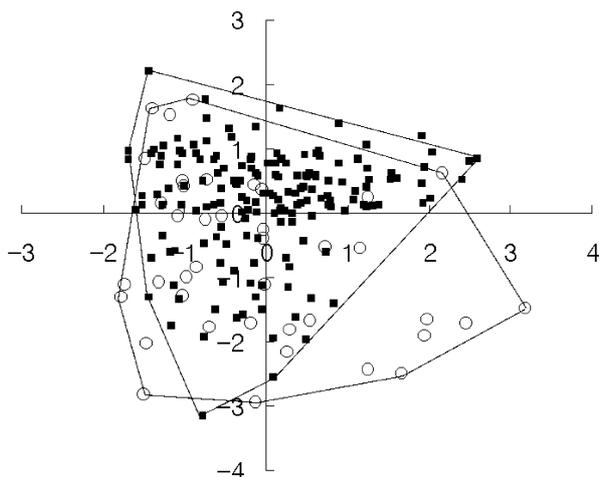


Figure 4. Principal components analysis (PCA) of 20 morphological characters measured on 109 OTUs and 80 leaves from one individual tree. Two extreme leaf shapes are shown. (A) geographic projection by PCA1 and PCA2 (+, China; Δ , individual tree; \bullet , Japan; \blacktriangle , Korea; \circ , Okinawa; \square , Russia); (B) a priori projection. (\circ , *Kalopanax septemlobus* var. *septemlobus*; \blacksquare , *Kalopanax septemlobus* var. *maximowiczii*).

Table 2. Loadings of the first three principal components for 20 morphological characters obtained by morphological analysis of *Kalopanax septemlobus*. Character numbers correspond to those in Table 1.

Character number	Components		
	Factor 1	Factor 2	Factor 3
1	0.49714	-0.34652	-0.42378
2	-0.33488	-0.24924	-0.23026
3	0.97691	-0.01139	-0.04212
4	0.87518	-0.09955	-0.05986
5	0.72576	-0.55093	0.34804
6	0.72093	-0.55557	0.32325
7	0.93238	0.22333	0.21591
8	0.09604	0.22726	-0.35525
9	0.68021	0.60321	-0.02863
10	0.81898	0.40065	-0.14449
11	0.85077	0.11918	-0.20761
12	0.82539	0.41652	-0.05190
13	0.86336	0.00990	-0.26705
14	0.94511	0.10966	0.19453
15	0.93959	-0.02287	0.04237
16	0.95290	0.10399	0.17726
17	0.94105	-0.03465	0.08469
18	-0.32189	0.55156	0.61100
19	-0.46058	0.38501	0.37926
20	0.26342	-0.86766	0.23230
Eigenvalue	11.24332	2.847965	1.424572
Cumulative percent	53.70	67.54	74.80

considerable degree of overlap, observable in frequency diagrams of incision degree [= ratio (depth of lobe/leaf length) (20)] (Figure 5A).

Examination of the relative magnitudes of the character coefficients for each principal component allowed the identification of the relative contribution of each character to the corresponding component (Table 2). The characters that contributed most to the loading on the first axis were leaf width (3), leaf length (7), length of first left lobe (14), length of second left lobe (15), length of first right lobe (16), and length of second right lobe (17). All leaf size characters were highly correlated with the first component axis. The characters that loaded most heavily on the second axis were the depth of left first lobe (5), the depth of first right lobe (6), width of center lobe (9) and the ratio (depth of lobe/leaf length) (20). The character that contributed most to the separation along the third axis was the leaf length/width ratio (18).

In order to examine the relationship between trichome character and cumulative values of variation generated, each of the 126 specimens was scored as either pubescent or glabrous (Figure 4B). That was glabrous individuals were assigned to the var. *septemlobus* group ($N=31$) and those with trichome to the var. *maximowiczii* group ($N=95$). The results of a PCA discarded the presence of two probable infraspecific groups, one with tufted villose indument at the basal axil of mature leaf surface vs. the other with glabrous to subglabrous abaxial leaf surfaces (var. *septemlobus*) (Ohashi, 1994). As expected, a lack of

phenetic coherence was evident in the multivariate analysis, and taxa assigned *a priori* were virtually inseparable in the projection. The analysis of frequency distribution of trichome density demonstrated that this variable showed a normal distribution (Figure 5B).

Discussion

Our initial examination of herbarium specimens suggested a high degree of morphological intergradation among the entities recognized within *Kalopanax septemlobus* and their inconsistent circumscription among the treatments of various authors. The morphometric analysis indicated that no strong discontinuities existed among the infraspecific taxa recognized in *Kalopanax septemlobus*. It also demonstrated that taxa within *K.*

septemlobus could not be delimited with the use of leaf characters. Morphological variation for all characters was continuous with a high degree of overlap across taxa. The difficulties of quantitatively visualizing shape differences could be seen by the fact that the distinction among OTUs was unclear and by the strong indication of similarity among the three geographic groups analyzed.

Comparisons of results of the univariate analyses which compared means and range for the geographic area showed a similarity between individuals assigned to subsp. *septemlobus* from southern China and those of subsp. *lutchuensis* from Okinawa. Figures 3 and 5 showed that some characters analyzed had ranges that overlapped completely, but had significantly different means [e.g. depth of first left lobe, length of second right lobe, ratio (length/width)]. Ohashi (1994) delimited taxa on the basis of slight differences in lobe number, and subsp. *lutchuensis* was distinguished by just one remaining character, leaf texture. Before formally recognizing these differences taxonomically, however, one would like to see evidence of a genetic basis and be assured that differences are not simply due to environmental factors. Geographic distribution should also be taken into consideration along with the analysis of morphological characteristics as a basis for evaluating relationships among taxa (Radford et al., 1974). In fact, variation of these characters was continuous and overlapped among OTUs from southern China and other areas, in particular Okinawa.

No clear distinction could be found between material assigned to the previously recognized var. *maximowiczii*, and to var. *septemlobus*, and forms intermediate in leaf morphology between these two taxa suggested that they should be united. The frequencies for the number of trichomes on the basal axil of the main nerves (Figure 5A) showed a normal distribution, suggesting that the degree of pubescence was related to polygenic traits. Although extreme values (glabrous/pubescence) were characteristic of some individuals, none of them could be reliably, consistently, and geographically distinguished based on this character alone. If other traits were to show correlation with a scarcity of trichomes, recognizing a form might be justified. For the two previously recognized taxa sympatric in eastern Asia (*K. septemlobus* var. *septemlobus* and var. *maximowiczii*), we did not confirm the constancy of characters under different environmental conditions, and thus could not determine their taxonomic values. Nevertheless, our data did not support the continued recognition of var. *magnificus* as distinct from typical material of *K. septemlobus*.

As noted in PCA, the coastal samples from western Korea appeared to be more variable and distinct compared to collections from other sites. These patterns of variation were consistent with the observation that deeply dissected lobed leaves dominated the coastal specimens. The pattern of variation could be environmentally induced and might reflect a degree of plasticity. However, variation in the coastal type was not sufficiently discontinuous to warrant taxonomic recognition.

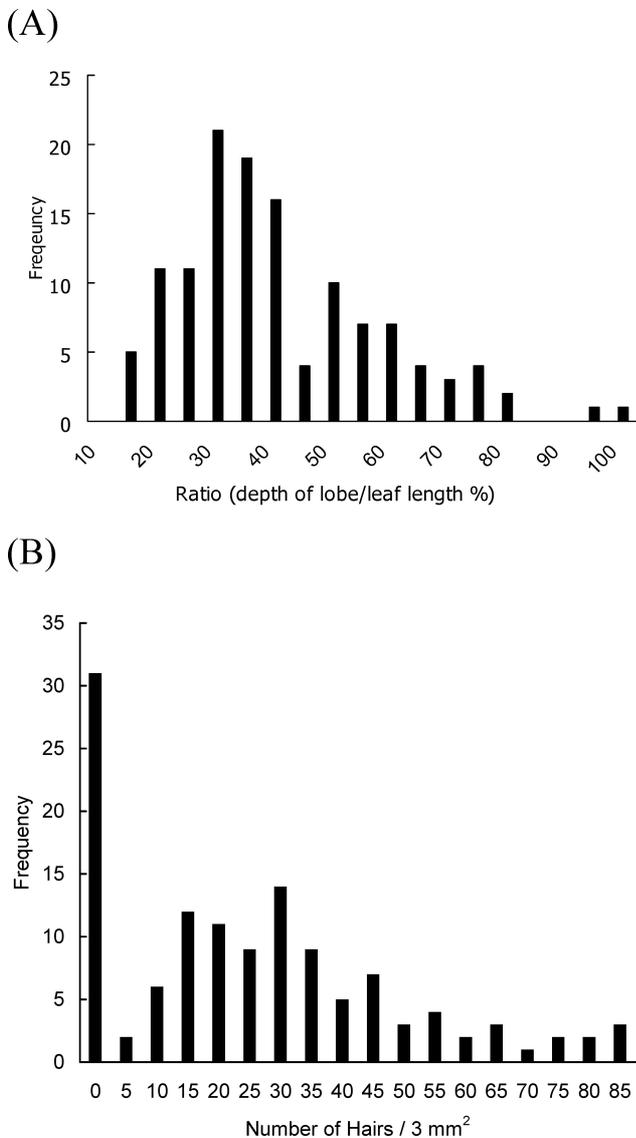


Figure 5. Histogram based on the frequencies of (A) the ratio of the first left depth / leaf length ratio and (B) frequencies of trichome density (number of hairs / 3 mm²).

The results of this study indicate a continuum in leaf morphology among the previously recognized infraspecific taxa. This continuum is especially evident in leaf lobing and pubescence, characters traditionally used to define infraspecific taxa within *K. septemlobus*. The material studied is not sufficiently differentiated to warrant the designation of subspecies or varieties, and our interpretation is in agreement with the taxonomic treatment of Ohashi (1994), except that we do not maintain subsp. *lutchuensis*.

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Appendix. Origin and accession number for specimens utilized for morphological analysis. All voucher specimens are deposited at Seoul National University, The Arboretum (SNUA) or as otherwise indicated.

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- CHINA:** Jiangxi Prov. *Ce-Ming Tan 95712* (TUS); Chekiang *anonymous 831* Aug. 1962 (PE); Chekiang PE *29274* (PE); Jiangxi PE *13479* (PE); Jiangxi *anonymous 2771* (PE); Hunan *L.H. Liu 9949* (PE); Hupei *C.F. Li 9498* (PE); Anwei PE *50502* (PE); Kansu *anonymous 3662* (PE); *s.l. anonymous 587* (PE); Shensi *H.W. Kung 2705* (PE); Shensi *T.N. Liou 11356* (PE); Liaoning PE *318065* (PE); Szechuan *anonymous 3499* (PE); Szechuan PE *105958* (PE); Szechuan *anonymous 2713* (PE); Szechuan *F. T. Wang 23635* (PE); Guangdong *L. Deng 5775* (PE); Guangxi PE *16716* (PE); Yunnan *P.H. Yu 880* (PE); Yunnan Salwin Valley, Pengta *T.T. Yu 23103* (PE); Shandong *Y.S. Cui 302* (PE); Liaoning *Y. Yabe s.n.* Aug. 14. 1917 (PE); Hopei *K.M. Liou 287* (PE); Hopei *H.F. Chow s.n.* ? 1930 (PE); Hopei *15210* (PE); Hopei Tungling *C.F. Li s.n.* ? 1929 (PE); Hopei Eastern tombs *J. Tang 2213* July 1931 (PE); Hopei Eastern tombs *K.C. Kuan 2213* (PE); Shensi *S.Y. Bao et al.* 168 (PE); Shensi *anonymous 604* (PE); Shandong Laoshan *C.Y. Chiao 2783* (PE); Shandong Laoshan *Y.C. Wang 773* (PE); Szechuan ? *2792* (PE); Szechuan *W.P. Fang et al.* *33045* (PE); Szechuan *T.P. Wang 8217* (PE); Szechuan *W.J. Zheng 1936* (PE); Szechuan *F. T. Wang 23635* (PE); Szechuan *F.T. Wang 21716* (PE); Szechuan Wan-Hsien *C.T. Hwa 76* (PE); Szechuan *W.P. Fang 3406* (PE); Szechuan PE *57574* (PE); Guizhou *S.Z. Jiang et al.* *32* (PE); Guizhou *Y. Tsiang 9074* (PE); Guizhou *C.Z. Yu 0621* (PE); Guangdong *Y. Tsiang 1466* (PE); Guangdong *Y. Tsiang 1347* (PE); Yunnan Changtien Plateau *G. Forrest 11256* (PE); Hunan *X.Y. Xi 454* (PE); Hupei PE *59176* (PE); Beijing *C.S. Chang 3889* (SNUA).
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東亞七裂葉刺楸（五加科）的形態數值分析

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七裂葉刺楸 (*Kalopanax septemlobus* (Thunb.) Koidz.) 係五加科中一木本植物，廣泛分布於東亞，而形態上相當多變。本研究針對標本館內的標本並輔以大量田野採得的葉片進行形態數值分析，以期釐清是否種內形態上的差異值得處理為不同的分類群。我們選用了可代表整個地理分布範圍的 126 個個體，記錄 20 項形態特徵，再將資料矩陣進行主成份分析。結果顯示七裂葉刺楸是一個多型性的種，目前所觀察到的不同的類型可能多係環境誘發的變異，顯示本種具有高度的環境上的可塑性。本研究並不支持之前所認定的各種內的分類群可具有分類上的位階。

關鍵詞：五加科；型；七裂葉刺楸；琉球七裂葉刺楸；形態數值分析；主成份分析。