

A Taxonomy of Korean Isopyroideae (Ranunculaceae)

Nam Sook Lee* and Sung Hee Yeau¹

Department of Biology, Research Institute for Life Sciences, College of Natural Sciences and

¹Department of Science Education, College of Education, Ewha Womans University, Seoul 120-750, Korea

Key Words:

Ranunculaceae
Korean Isopyroideae
Principal components
analysis
Cluster analysis

To discuss the taxonomic dispositions of Korean Isopyroideae (Ranunculaceae) taxa, principal components analysis and cluster analysis were performed using quantitative and qualitative morphological characters. The principal components analysis revealed that the size and number of ovule, ovary width, ratio of style length/ovary length, filament length, sepal size, style length, leaf size, and ovary length are important characters to distinguish Korean Isopyroideae taxa. The cluster and principal components analyses based on both quantitative and qualitative characters demonstrate that *Isopyrum mandshuricum* is more closely related to *Enemion raddeanum* than to *Semiaquilegia adoxoides*. Even though *Enemion* is not separated from *Isopyrum* by quantitative characters, they are distinguished by qualitative characters, suggesting that four taxa, *Enemion*, *Semiaquilegia*, *Isopyrum* and *Aquilegia*, should be recognized in Korean Isopyroideae. In addition, cluster analyses suggest that *S. adoxoides* could be separated from *Aquilegia buergeriana* var. *oxysepala*.

The Ranunculaceae have worldwide distributions, although many genera and species are centered in the temperate zone of East Asia. Composed of 58 genera and 3000 species, the family is divided into two to six subfamilies depending on the authors (Bentham and Hooker, 1873; Engler and Prantle, 1891; Nakai, 1952; Tamura, 1962, 1966; Buchheim, 1964; Satake et al., 1983). The subfamily Isopyroideae is characterized by small T-type chromosomes, a basic chromosome number of $x=7$, and follicular fruits (Tamura, 1966, 1967, 1968; Satake et al., 1983). In Korea, four taxa of Isopyroideae have been recognized; *Isopyrum mandshuricum* (Kom.) Kom., *Enemion raddeanum* (Regel) Maxim., *Semiaquilegia adoxoides* (DC.) Makino, and *Aquilegia buergeriana* var. *oxysepala* (Trautv. et Meyer) Kitamura. The taxonomic treatments and generic disposition of these taxa, however, have long been controversial.

Isopyrum mandshuricum was first described as *Semiaquilegia mandshurica* by Komarov in 1926, and transferred to *Isopyrum* by himself in the same year (Hill, 1933). *Isopyrum yamatsutanum* Ohwi (1932) is a synonym for the species. *Isopyrum mandshuricum* was first recorded in Korea by Lee (1974) as *Semiaquilegia mandshurica* Kom. based on a specimen collected from Baek Bong in the central part of Korea. It was also collected from Mt. Chonma, Mt. Myung-ji, Mt. Chukryung, Mt. Wha-Ya, and Young-dong in Chungbuk Province. The taxon here recognized as *Isopyrum mandshuricum* has been assigned to either *Semia-*

quilegia or *Isopyrum* depending on the authors. The distinguishing character between the two genera is the presence (*Semiaquilegia*) or absence (*Isopyrum*) of staminodia (Tamura, 1968; Tamura and Lauener, 1968). Lee (1976, 1996) assigned the taxon to *Semiaquilegia* together with *S. adoxoides* mainly on the basis of saccate petals. He distinguished the former from the latter by its light, yellow flowers and many small tubers. The genus *Isopyrum* has been divided into two sections; sect. *Isopyrum* with flat petals and sect. *Paropyrum* with tubulose petals. Section *Paropyrum*, which includes *I. mandshuricum* and *I. anemonoides*, is more primitive than sect. *Isopyrum*, and it was suggested that *Semiaquilegia* is derived from the latter (Tamura, 1968; Tamura and Lauener, 1968). Later, Tamura (1992) divided the genus *Isopyrum* into four sections; sect. *Isopyrum* with *I. thalictroides*, sect. *Manshuria* with *I. mandshuricum*, sect. *Paropyrum* with *I. anemonoides*, and sect. *Alexeya* with *I. ludlowii*. The generic delimitation of *Isopyrum* and *Enemion* has also long been controversial. *Enemion raddeanum* was placed in the genus *Enemion* based on the absence of petals by Rafinesque in 1820 (Bentham and Hooker, 1873), a decision supported by Drummond and Hutchinson (1920), Tamura (1968), and Keener (1977). However, Calder and Taylor (1963) suggested that the presence or absence of the petal is not an important character to distinguish *Enemion* from *Isopyrum*, and included *E. raddeanum* within the genus *Isopyrum* along with other species which have petals. Hoot (1995) also treated *Enemion biternatum*, which lacks petals, as *Isopyrum biternatum*.

Semiaquilegia adoxoides belongs to *Aquilegia* as a

* To whom correspondence should be addressed.
Tel: 82-2-360-2366, Fax: 82-2-360-2385
E-mail: namsook@mm.ewha.ac.kr

Table 1. Taxonomic treatments of four taxa of Korean Isopyroideae

Taxon (local name)	Reference
<i>Semiaquilegia mandshurica</i> Kom.	Komarov (1926), Lee, Y. N. (1976)
<i>Isopyrum mandshuricum</i> (Kom.) Kom. (Manju-baramkkot)	Komarov (1926), Hsiao (1979), Tamura (1968, 1992), Lee, T. B. (1980)
<i>Enemion leveilleanum</i> Nakai ex Mori	Nakai (1952)
<i>E. raddeanum</i> Regel	Annee (1861), Drummond and Hutchinson (1920), Tamura (1968), Tamura and Lauener (1968) Hsiao (1979), Fu (1990)
<i>Isopyrum raddeanum</i> (Regel) Maxim. (Nado-baramkkot)	Calder and Taylor (1963), Lee, T.B. (1983), Ohwi (1984)
<i>Semiaquilegia adoxoides</i> (DC.) Makino	Makino (1902), Drummond and Hutchinson (1920), Hsiao (1979), Lee, T. B. (1980) Satake et al. (1983)
<i>Aquilegia adoxoides</i> (DC.) Ohwi (Gaeguribaltop)	Ohwi (1984)
<i>Aquilegia buergeriana</i> var. <i>oxysepala</i> (Maebaltopkkot)	Annee (1861), Lee, Y.N. (1976), Hsiao (1979), Lee, T.B. (1980), Ohwi (1984)

congener of *A. buergeriana* var. *oxysepala* on the basis of petals with spurs (Ohwi, 1984). The differences of the two taxa, however, are described as follows: "*Semiaquilegia* has saccate petals which lack stalks, has a floral diameter of 5 mm, and 2-5 carpels, while *Aquilegia* has long-spurred petals, a floral diameter of 2.5-4 cm, and 5 carpels" (Lee, 1976; Hsiao, 1979; Lee,

1980; Satake et al., 1983). Recently, Fu (1990) studied pollen of Isopyreae, and Hoot (1991) studied the phylogeny of the Ranunculaceae based on the micro-morphological characters of the leaf epidermis, gross morphology, and cladistic analysis. However, all of the Korean Isopyroideae taxa were not included in these studies, and several small genera, such as *Semia-*

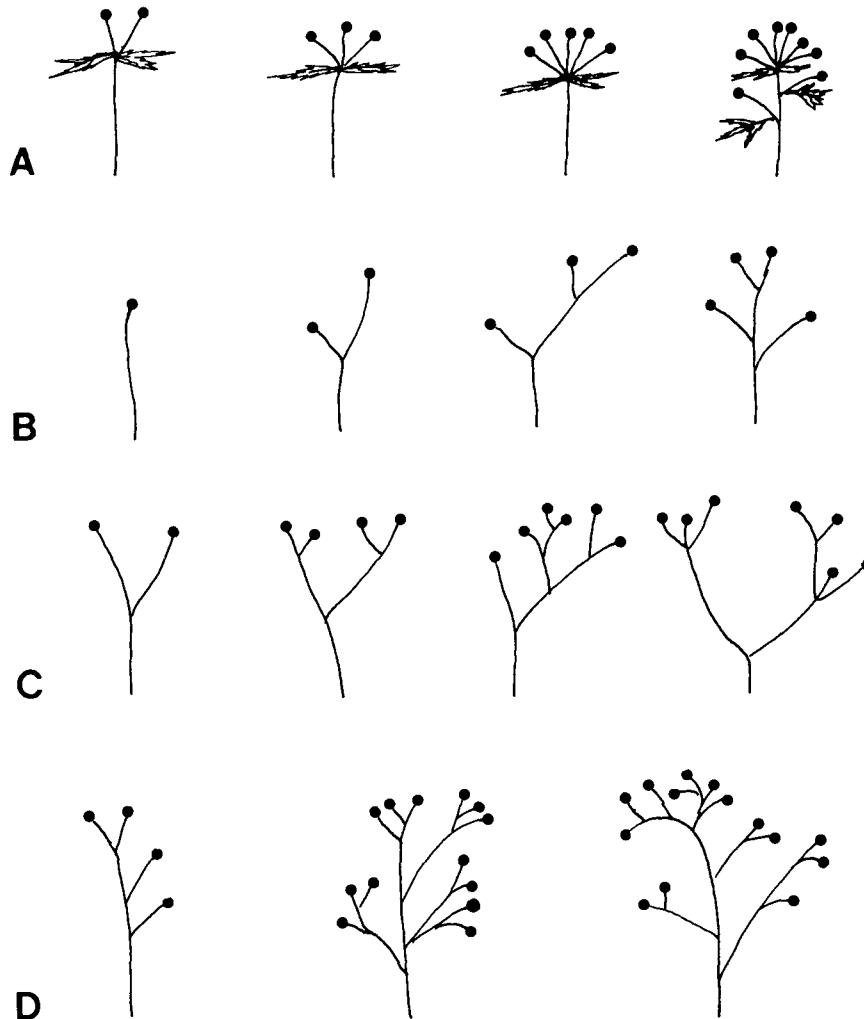


Fig. 1. Inflorescences of Korean Isopyroideae. A, *Enemion raddeanum*. B, *Isopyrum mandshuricum*. C, *Semiaquilegia adoxoides*. D, *Aquilegia buergeriana* var. *oxysepala*.

Table 2. Quantitative morphological characters used for numerical analyses of Korean Isopyroideae

Character no	Character
1	Plant height (cm)
2	Petiole length (cm)
3	Leaf length (first leaf from the bottom of stem)(cm)
4	Leaf width (cm)
5	character 4/character 3
6	Number of flowers (no.)
7	Number of sepals (no.)
8	Sepal length (mm)
9	Sepal width (mm)
10	Number of stamens (no.)
11	Filament length (mm)
12	Anther length (mm)
13	Number of pistils (no.)
14	Ovary length (mm)
15	Ovary width (mm)
16	Style length (mm)
17	Character 16/character 14
18	Number of ovules (no.)
19	Ovule length (mm)
20	Ovule width (mm)

quilegia and *Enemion*, were not represented.

Consequently, the classification and relationships of taxa within the Isopyroideae in Korea remain unclear and two to four genera have been traditionally recognized depending on the emphasis placed on the major morphological characters (Table 1 and Fig. 1). In this study, we have examined morphological characteristics of the four Korean species to discuss their taxonomic dispositions and relationships and to determine the key characteristics within the Korean Isopyroideae.

Materials and Methods

For the study of Korean Isopyroideae, *Isopyrum mandshuricum*, *Enemion raddeanum*, *Semiaquilegia adoxoides*, and *Aquilegia buergeriana* var. *oxysepala* were collected from 1991 to 1994. Specimens deposited at SNU, SKK, and JNU were also examined (Appendix). Twenty quantitative morphological characters (Table 2) were examined from 77 individuals representing four taxa (Appendix). To analyze patterns of morphological variation, principal components analysis and cluster analysis of 77 OTUs were performed with 20 quantitative characters using NTSYS (ver. 1.70) on an IBM compatible personal computer. In addition, 12 qualita-

tive characters (Table 3) were analyzed by cluster analysis in order to examine taxonomic relationships among the Korean Isopyroideae taxa.

Leaf epidermal characters were examined from the median lobe of the basal leaf using a light microscope and a scanning electron microscope.

Results

Morphological characters

Roots: Roots of *E. raddeanum* are fibrous. *Isopyrum mandshuricum* and *S. adoxoides* have tuberous roots; the former has many small tuberous roots, but the latter has a large one. *Aquilegia buergeriana* var. *oxysepala* has well-developed tap roots.

Leaves and Bracts: Basal leaves of *E. raddeanum* and *S. adoxoides* are ternate. *Isopyrum mandshuricum* has ternate or biternate leaves, and *A. buergeriana* var. *oxysepala* has biternate leaves. All taxa have distinctive petioles. Tiny bractlike scales are absent in *A. buergeriana* var. *oxysepala*, but present in the other three species.

Inflorescences: The inflorescence of *I. mandshuricum* is a simple cyme with 1-4 terminal flowers facing upward. *E. raddeanum* has an umbelliform cyme with flowers facing upward. When the cyme is terminal, it consists of 2-8 flowers, but it usually has 1 or 2 flowers when it is axillary. *Semiaquilegia adoxoides* has an axillary or terminal simple or dichasial cyme with 2-19 flowers facing downward. *Aquilegia buergeriana* var. *oxysepala* has a dichasial cyme with 4-14 flowers which open downward (Fig. 1).

Perianth: The perianth of *E. raddeanum* is not differentiated, white, elliptic, 4-5 in number, 7-8 mm long, and 3-4.2 mm wide. The perianth consists of a single cycle of tepals as in *Clematis* and *Anemone*, even though they look like petals (Fig. 2). *Isopyrum mandshuricum* has well-differentiated sepals and petals. Sepals are petaloid, white, and larger than petals. The sepals are 5 or 6, 4.5-10 mm in length, and 3.0-3.8 mm in width. Petals are white, 5 or 6, spurless,

Table 3. Characters and character states used in the cluster analyses of Korean Isopyroideae

Character	Taxon			
	ENE ¹	ISO ²	SEM ³	AQU ⁴
0	2	2	1	Root type: 0=fibrous, 1=tap, 2=tuberous
0	0	0	1	Involucre on peduncle: 0=absent, 1=present
0	1	1	1	Inflorescence: 0=umbell cyme, 1=simple or dichasial cyme
0	0	1	1	Direction of flowering: 0=upward, 1=downward
0	0	1	1	Pedicel pubescence: 0=glabrous, 1=pubescent
0	0	0	1	Sepals : 0=white, 1=colorful
0	1	2	3	Petals: 0=absent, 1=saccate, 2=saccate and short spur, 3=long spur
0	1	1	0	Stalk of petal: 0=absent, 1=present
0	0	1	1	Staminodia (sterile scale): 0=absent, 1=present.
0	0	0	1	Pistil pubescence: 0=glabrous, 1=pubescent
0	1	0	0	Pistil stalk: 0=absent, 1=present
0	1	0	1	Slope of follicle: 0=horizontal, 1=ascending or erect

¹*Enemion raddeanum*; ²*Isopyrum mandshuricum*; ³*Semiaquilegia adoxoides*; ⁴*Aquilegia buergeriana* var. *oxysepala*.



Fig. 2. Variation of floral parts in Korean Isopyroideae. A, *Isopyrum anemonoides*. B, *Enemion raddeanum*. C, *Isopyrum mandshuricum*. D, *Semiaquilegia adoxoides*. E, *Aquilegia buergeriana* var. *oxysepala*; s, sepal; p, petal; g pistil; a stamen; sa, staminode. Scale bars=5 mm.

saccate at the base, born on short stalks, 2-3.6 mm in length, and 1.1-1.6 mm in width. Sepals of *Semiaquilegia adoxoides* are white, 5 or 6, larger than the petals, showy, petaloid, 5-6 mm long, and 2-3 mm wide. Petals of this species are white, 5 or 6, saccate at the base, slightly spurred, with short and thick stalks, 2-4 mm long, and 0.8-1.3 mm wide. The inner wall of the perianth is 1/3 of outer wall length (Figs. 2, 3). Sepals of *A. buergeriana* var. *oxysepala* are wine-red, longer than the limb of petals. Petals of this taxon are yellow, with incurved wine-red spurs at the base and without stalks (Fig. 2).

Stamens: All taxa have numerous stamens. However, staminodia are present in *Aquilegia* and *Semiaquilegia*, and absent in *Enemion* and *Isopyrum*. Tamura (1968) distinguished Isopyroideae into two subtribes based on the staminodia between the androecium and gynoecium. Aquilegiinae has staminodia but Isopyrinae does not (Fig. 2).

Pistils: Carpels of *I. mandshuricum* are (1-)2, stalked, with slender straight styles. The beak of the carpel is 1.0-1.2 mm long. Carpels of *E. raddeanum* are 3-6, stalkless, and the beak of carpel is slightly shorter than the ovary, 1.0-1.6 mm long. Carpels of *S. adoxoides*

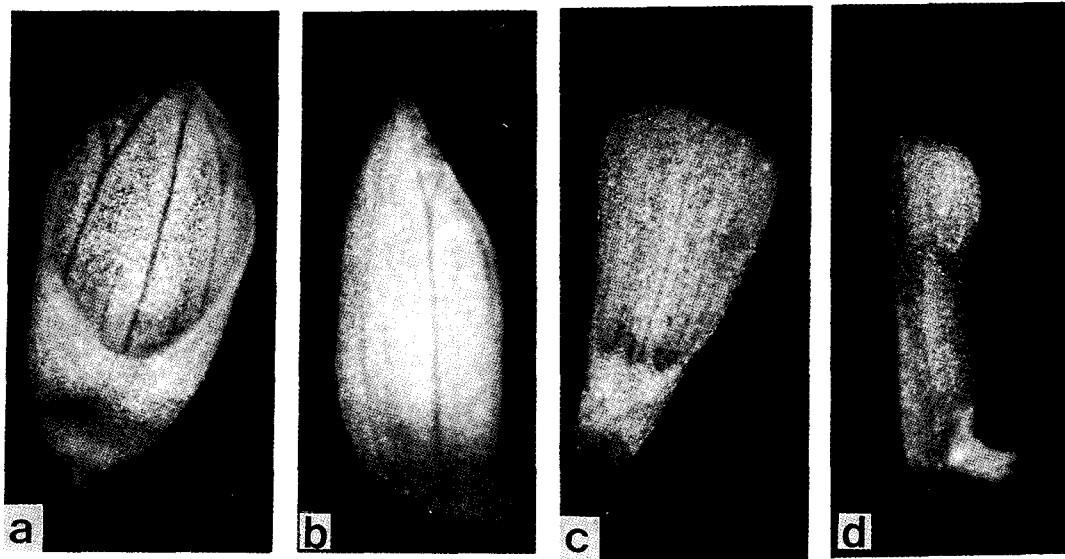


Fig. 3. Petals of *Isopyrum mandshuricum* (a, b) and *Semiaquilegia adoxoides* (c, d). a and c, frontal view; c and d, lateral view.

are 2-4, stalkless, and with styles much shorter than the ovary. In *Aquilegia*, carpels are 3-5, pubescent, and with long and straight styles (Fig. 2).

Follicles: Follicles of *I. mandshuricum* and *A. buergeriana* var. *oxysepala* are matured obliquely, but those of *E. raddeanum* and *S. adoxoides* are matured horizontally. The number of seeds is 2 per follicle in *I. mandshuricum* and *E. raddeanum*, but 5 to 12 in *S. adoxoides*. *Aquilegia buergeriana* var. *oxysepala* produces ca. 30 seeds in each follicle.

Trichomes: All taxa of Korean Isopyroideae produce trichomes on the abaxial surface of basal leaves. Four types of trichomes were observed: Linear trichomes (Type 1) which are slender, long-filiform with the width of the upper part and lower part nearly equal; swollen base trichomes (Type 2), unicellular or multicellular; Club-shaped trichomes (Type 3) with concave bases and swollen tips; pear-shaped trichomes (Type 4) with or without swollen bases (Fig. 4). The length of each trichome type varies. The distribution of the trichome types among the taxa is summarized in Table 4.

Distribution: The habitats of *A. buergeriana* var. *oxysepala* are at high and low places of mountains in the Korean peninsula, and *E. raddeanum* grows mainly in the mid-slope of mountains northward of the Kyung-buk Province. The habitat of *I. mandshuricum* is limited to low places of mountains from the north of Mt. Chuheul in Chung-buk Province to Manchuna. *S. adoxoides* is distributed in low places from the southern part of the Korean peninsula to Japan (Fig. 5).

Principal components analysis and cluster analysis

The first three principal components (PC's) accounted

for approximately 73% of the total variance; PC 1 contributed 31.27%, and ovule width (20), ovule length (19), and the number of ovules (18), ovary width (15), style length/ovary length (17), and filament length (11) have relatively high vector loadings. PC 2 accounted for 26.01%, and reflected high loadings for sepal width (9), sepal length (8), style length (16), and leaf width/leaf length (5). PC 3 contributed 15.54%, and was related to leaf length (3), ovary length (14), and leaf width (4) (Table 5).

A three-dimensional plot of the first three principal components clearly revealed the presence of four taxa in Korean Isopyroideae (Fig. 6). *Aquilegia buergeriana* var. *oxysepala* and *S. adoxoides* are clearly separated from *E. raddeanum* and *I. mandshuricum* on the first component. Individuals of *A. buergeriana* var. *oxysepala* are distinguished from those of *S. adoxoides* on the second component. In the plot, individuals of *E. raddeanum* are separated from those of *I. mandshuricum* on the third component with little overlap by the first two principal components (Fig. 6).

UPGMA cluster analysis of Korean Isopyroideae based on quantitative characters resulted in two major groups; *A. buergeriana* var. *oxysepala*-*S. adoxoides* cluster and *E. raddeanum*-*I. mandshuricum* cluster (Fig. 7). In

Table 4. Trichome types and their distributions in Korean Isopyroideae taxa*

	ISO**	ENE	SEM	AQU
Type 1	-	-	+	+
Type 2	+	+	-	+
Type 3	+	-	-	-
Type 4	+	+	+	-

*Type 1, Linear; Type 2, Swollen base; Type 3, Club-shaped; Type 4, Pear-shaped

**See table 3 for taxon abbreviations

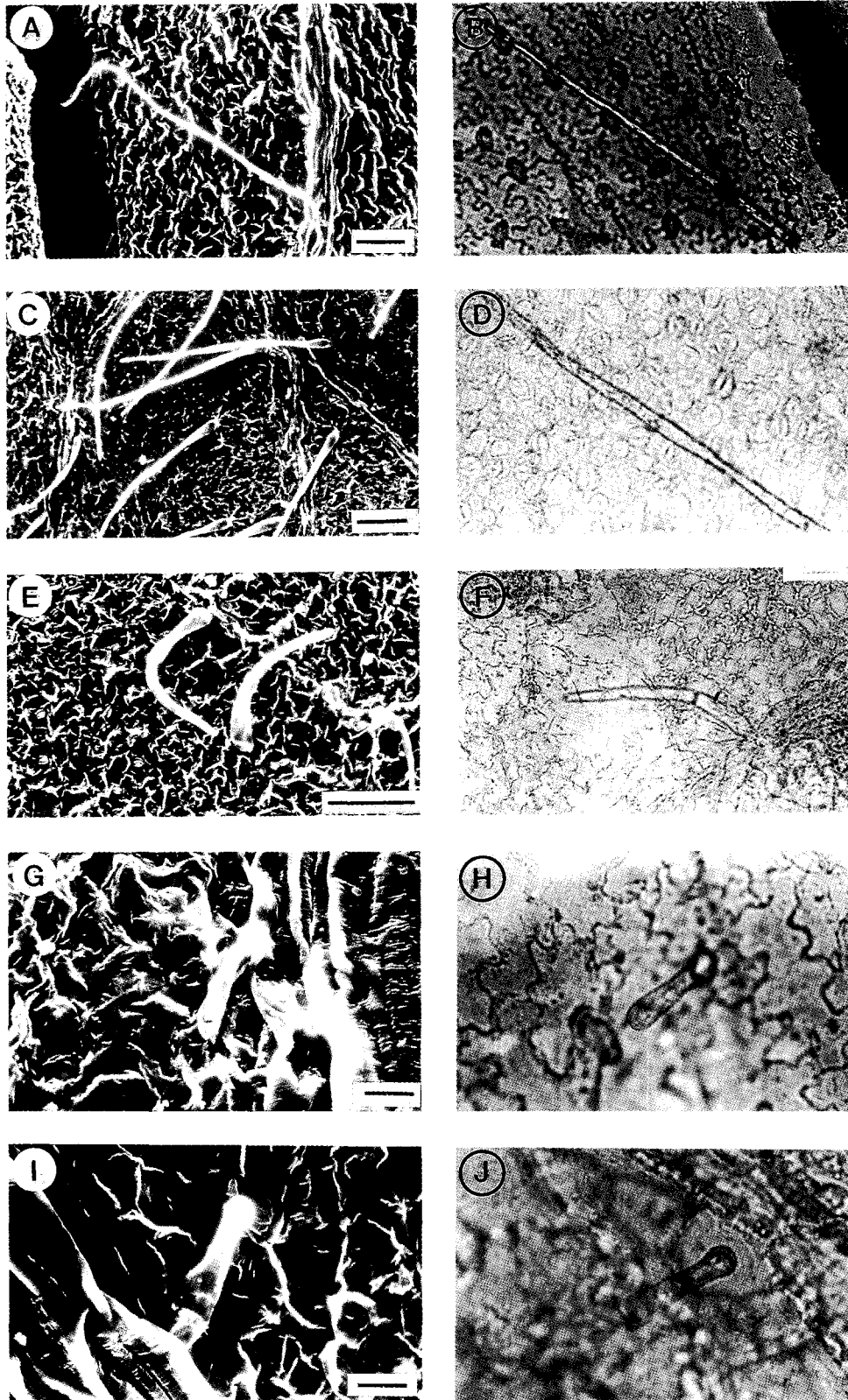


Fig. 4. SEM (A, C, E, G, I) and LM (B, D, F, H, J) photomicrographs of trichomes found in Korean Isopyroideae. A, B, *Semiaquilegia adoxoides* (Type 1); C, *Isopyrum mandshuricum* (Type 2, unicellular); D, *Aquilegia buergeriana* var. *oxysepala* (Type 2, unicellular); E, F, *Enemion raddeanum* (Type 2, multicellular); G, H, *I. mandshuricum* (Type 3); I, *I. mandshuricum* (Type 4); J, *S. adoxoides* (Type 4). Scale bars=10 μ m (G-J) and 100 μ m (A-F).

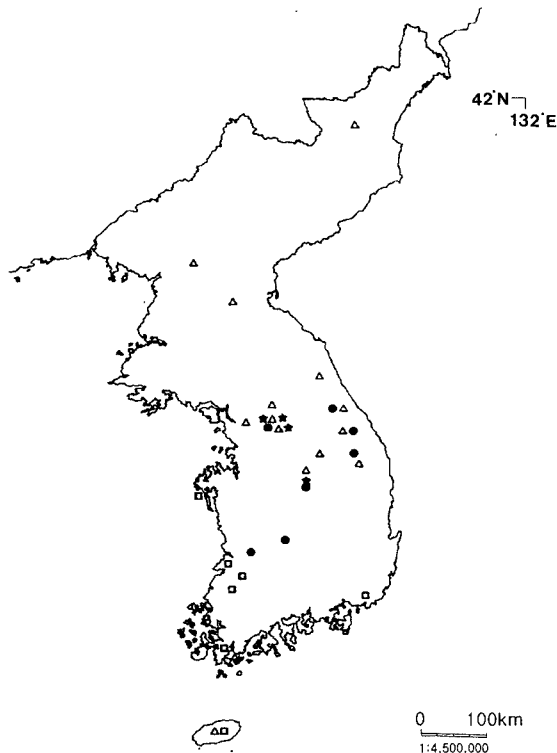


Fig. 5. Distribution of four Korean Isopyroideae taxa. Δ , *Aquilegia buergeriana* var. *oxyssepala*; \square , *Semiaquilegia adoxoides*; \star , *Isopyrum mandshuricum*; \bullet , *Enemion raddeanum*. Voucher specimens are listed in the Appendix.

the first cluster, individuals of *A. buergeriana* var. *oxyssepala* form a distinctive cluster from one formed by individuals of *S. adoxoides*. In the second cluster, individuals of *E. raddeanum* are fairly well-separated

Table 5. Loadings of the first three principal components (PC) for 20 characters from the analysis of 77 individuals of the Korean Isopyroideae taxa

Character	PC 1	PC 2	PC 3
1	0.28497	-0.67672	0.26759
2	-0.29058	-0.09281	0.05073
3	-0.29948	0.13444	0.85942
4	-0.35008	-0.17088	0.75155
5	-0.54164	-0.68492	-0.26673
6	0.39080	-0.59562	0.04798
7	-0.37280	-0.64942	-0.39998
8	0.19946	0.86985	-0.35797
9	-0.10981	0.91525	0.02302
10	-0.59095	0.66809	0.00850
11	-0.74765	0.12420	-0.07577
12	-0.64728	-0.15769	-0.47468
13	-0.03533	-0.63259	0.48166
14	0.02267	-0.41017	-0.76284
15	-0.85464	-0.26959	-0.31141
16	0.02669	0.82896	-0.19956
17	-0.75402	0.14295	0.38761
18	0.90339	-0.11559	-0.17831
19	-0.94625	-0.00592	-0.04572
20	-0.94799	-0.02070	-0.04776
Eigenvalue	6.25359	5.20293	3.10798
Cumulative % of eigenvalues	31.27	57.28	72.82

from those of *I. mandshuricum* with some individuals intermixed (Fig. 7). Also, UPGMA-derived phenogram based on qualitative characters showed that *I. mandshuricum* is clustered with *E. raddeanum*, and then linked to *S. adoxoides*. *Aquilegia buergeriana* var. *oxyssepala* is connected to them at the base of the phenogram (Fig. 8).

Discussion

On the basis of the number of carpels and apetalous flowers, Drummond and Hutchinson (1920) suggested that *Paraquilegia* is most primitive, and *Enemion* was derived by the reduction or loss of petals, and then the evolution of *Isopyrum* was accompanied by the reduction in the number of carpels to two. Tamura (1962, 1968) held the opinion that petals were derived from taxa lacking petals. He insisted that a long petal claw is primitive to a short claw and flat-bladed petals gave rise to spurred petals (Tamura, 1962, 1968). He proposed that a common ancestor of Isopyroideae lacking petals and apocarpous as in *Enemion* evolved to *Dichocarpum* with primitive petals, and then *Isopyrum* with fully formed petals (Tamura, 1968). Tamura (1992) also suggested that *Enemion* should be separated from *Isopyrum*. In addition, Keener (1977) did not place *E. biternatum* lacking petals in the genus *Isopyrum*, but in *Enemion*. However, Calder and Taylor (1963) stated that the petaloid structure previously recognized by Drummond and Hutchinson (1920) are staminodia in origin. They claimed that *Enemion* can not be separated from *Isopyrum* because too much emphasis has been placed on the presence or absence of petals in separating them (Calder and Taylor, 1963). The three-dimensional plot of individuals projected on the first three components revealed that *E. raddeanum* and *I. mandshuricum* are separated by the third component, which is primarily a function of characters related to the size of leaves and the length of the ovary (Table 5, Fig. 6). *Semiaquilegia adoxoides*, treated as a member of the genus *Aquilegia* by Ohwi (1984), and *A. buergeriana* var. *oxyssepala* are closely related on the basis of staminodia within the rows of stamens. However, Fu (1990) considered that these two genera are quite different in petal type, which may be the result of parallel evolution. In *A. buergeriana*, the petals are spurred and stalkless. Lower margins of petals are never connate and the spur is formed by an abaxial extension of the lower part of the petal. In *Semiaquilegia*, the cupular petals appear to be peltate with a shorter stalk and the "cup" seems to be formed by an adaxial fusion of lower margins of petals. Fu (1990) also considered that the evolutionary progress has occurred from *Calathodes* to *Semiaquilegia* through *Enemion*, *Isopyrum*, and *Leptopyrum* in one lineage. In the other lineage, *Aquilegia* were derived from *Paraquilegia* via *Urophyssa*. Principal components analysis revealed that four taxa of Korean Isopyroideae can be

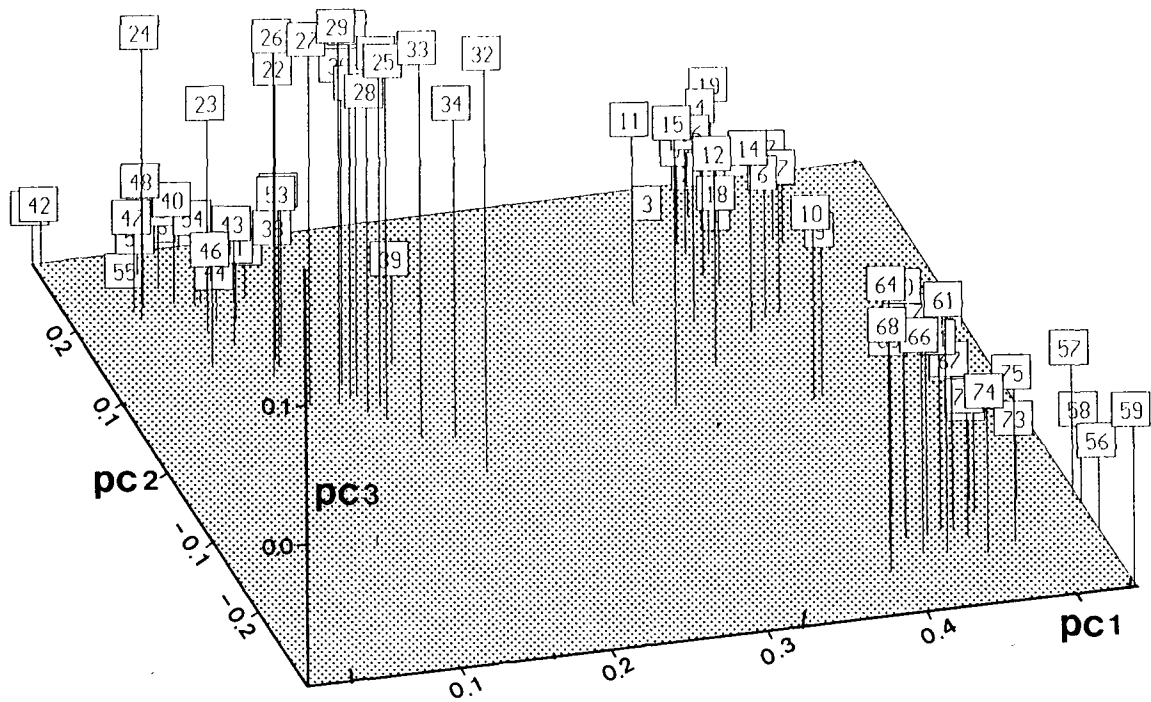


Fig. 6. Three-dimensional plot of principal components analysis of Korean Isopyroideae based on quantitative characters. OTU numbers correspond to specimen numbers in the Appendix. 1-20, *Aquilegia buergeriana* var. *oxyssepala*; 21-35, *Enemion raddeanum*; 36-55, *Isopyrum mandshuricum*; 56-77, *Semiaquilegia adoxoides*.

recognized (Fig. 6). The separation of *A. buergeriana* var. *oxyssepala* and *S. adoxoides* from *E. raddeanum* and *I. mandshuricum* by the first component indicates that the former two taxa are distinguished from the latter two by the shape of the pistil and the length of the filament. In addition, *A. buergeriana* var. *oxyssepala* are separated from those of *S. adoxoides* by the second component, which is primarily related to the size of the sepal, style length and leaf shape.

Even though cluster analyses of Korean Isopyroideae based on quantitative characters and qualitative characters showed different topologies, it might have resulted from a small number of characters and allocation of some characters to quantitative or qualitative character. Both cluster analyses showed that *I. mandshuricum* is more closely related to *E. raddeanum* than to *S. adoxoides*. In addition, cluster analyses suggest that *S. adoxoides* could be separated from *A. buergeriana* var. *oxyssepala* (Figs. 7, 8).

For the types of trichome in the Ranunculaceae, Hoot (1991) recognized four types: Type 1. Linear; type 2. Swollen base and sometimes with swollen tip; type 3. Club-shaped; and type 4. Pear-shaped with round tip. It was also reported that "type 2" and "type 4" are present in *A. buergeriana* var. *oxyssepala*, and "type 1" and "type 4" are present in *Isopyrum*. However, this study showed that *A. buergeriana* var. *oxyssepala* does not have "type 4" trichomes and *I. mandshuricum* has "type 2", "type 3" and "type 4"

trichomes instead of "type 1" and "type 4" which were observed in *I. biternatum* by Hoot (1991). In this study, "type 3" trichome was not found in *E. raddeanum* which was treated as a congener of *I. mandshuricum*, *S. adoxoides* and *A. buergeriana* var. *oxyssepala*. Therefore, this result supports that *I. mandshuricum* could be distinguished from *E. raddeanum* by the presence of "type 3" trichomes.

In conclusion, morphological analyses suggest that there are four taxa in Korean Isopyroideae, *A. buergeriana* var. *oxyssepala*, *E. raddeanum*, *I. mandshuricum*, and *S. adoxoides*. Principal component analysis (Fig. 6, Table 5) indicates that quantitative characters are important to distinguish Korean Isopyroideae taxa, such as the size and number of ovule, ovary width, ratio of style length/ovary length, filament length, sepal size, style length, leaf size, and ovary length. The phenogram based on quantitative and qualitative characters showed *I. mandshuricum* is more closely related to *E. raddeanum* than to *S. adoxoides*.

Acknowledgements

The authors thank Prof. Richard Whitkus, Prof. Youngbae Suh and Prof. Chong-Wook Park for their help with the manuscript, Prof. Byung Yun Sun, Prof. Bong Sob Kil for collecting plant samples, Prof. Sara B. Hoot for reference, and Miss Ji-Hyun Kim and Min-Ju Kim for assistance. This work was supported by KOSEF grant 941-0500-051-2.

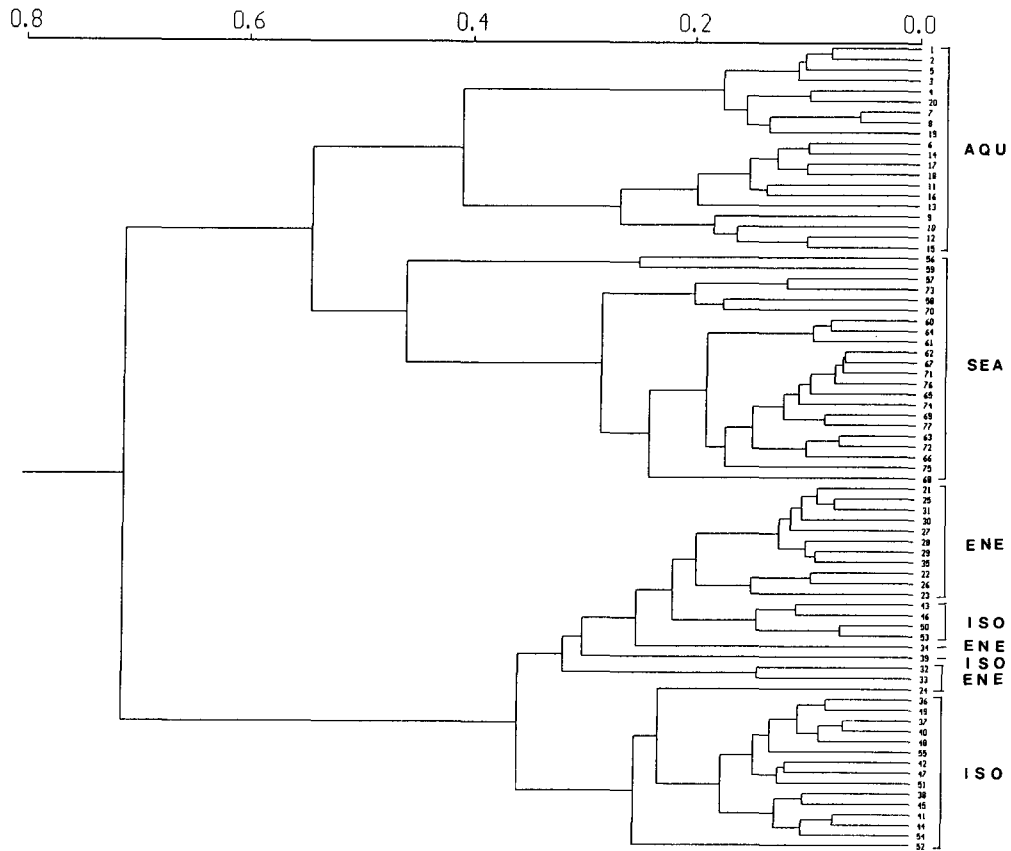


Fig. 7. UPGMA phenogram for 77 OTU's of Korean Isopyroideae taxa based on average taxonomic distance computed from quantitative characters. OTU numbers correspond to specimen number in the Appendix. 1-20 (Δ): *Aquilegia buergeriana* var. *oxysepala*; 21-35 (\square): *Enemion raddeanum*; 36-55 (\star): *Isopyrum mandshuricum*; 56-77 (\bullet): *Semiaquilegia adoxoides*.

Appendix

Collection data and voucher specimens used for the morphological study of Korean Isopyroideae (The

squared numbers before each locality represents the individual numbers used in numerical analyses).

Aquilegia buergeriana var. *oxysepala*: Korea-[1-2]: Mt.

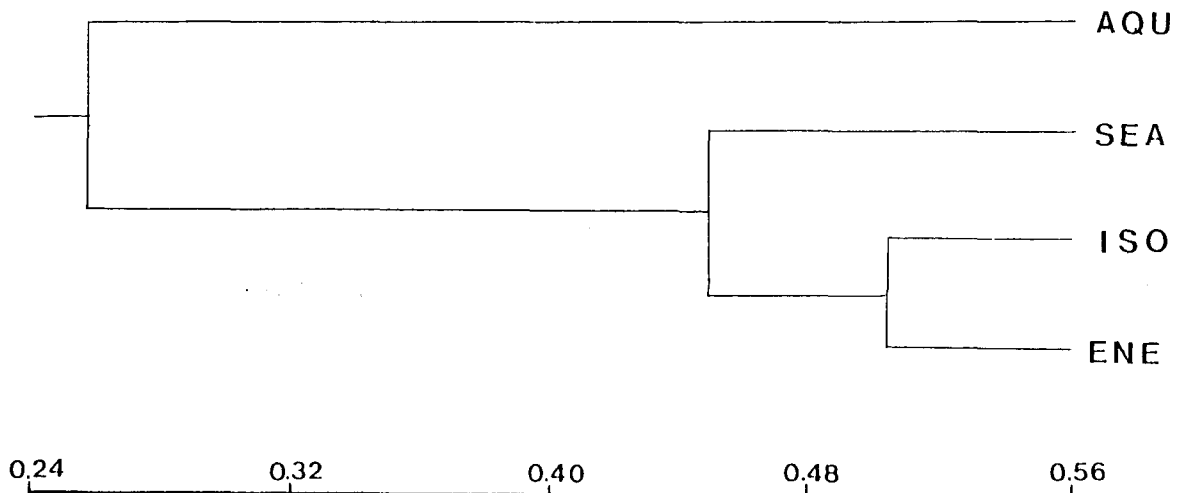


Fig. 8. UPGMA phenogram of Korean Isopyroideae taxa based on simple matching coefficient from qualitative character. Taxon acronyms correspond to those in Table 3.

Sori (May 26, 1990. Jung, Yun, Cho and Shin. SKK 2992); [3]: Mt. Sori (Jun. 2, 1990. Oh. SKK 2998); [4-5]: Mt. Sori (May 26, 1990. Jung, Yun, Cho and Shin. SKK 2992); [6]: Mt. Sori (May 20, 1989. Lee. SKK 28); [7]: Mt. Sori (May 26, 1990. Jung, Yun, Cho and Shin. SKK 2992); [8]: Mt. Sori (May 6, 1990. Lee. SKK 2991); [9-10]: Mt. Bon-am (May 29, 1988. Min and Park. SKK 3004); [11-13]: Mt. Odae (Jun. 3, 1990. Seol, Seo and Sung SKK 2997); [14]: Mt. Odae (Jun. 2, 1990. Park. SKK 2993); [15]: Mt. Chiak (Jun. 6, 1990. Kang. SKK 2999); [16-17]: Mt. Chiak (Jun. 3, 1989. So and Yu. SKK 3010); [18]: Mt. Halla (Jul. 2, 1984. Lee and Park. SKK 3008); [19-20]: Mt. Yongmun (Jun. 2, 1990. Lee and Lee. SKK 2995); Mt. Wolak (Apr. 30, 1989. ?. SKK 2988); Mt. Taebaek (Aug. 14, 1966. Lee. SKK 2984); Mt. Myowhyang (Jul. 20, 1938. Do and Shim. SNU 2591); Peak Kwanmo (Jul. 16, 1936. Do. SNU 2590); Sambang (Jun. 10, 1933. Do. SNU 2617); Yangduk (May 5, 1943. Do and Shim s.n. SNU); Mt. Kwanak (May, 22, 1981. Nam. 1981. SNU 52910); Mt. Daeam (Jul. 4, 1967. Chung and Kang. SNU 41015); Mt. Chombong (May 24, 1968. Chung. SNU 2385)

Enemion raddeanum: Korea-[21-23]: Kohan (May. 15, 1991. Lee and Yeau. EWH-No.C10); [24]: Mt. Odae (May. 18, 1987. Lee s.n. EWH); [25]: Mt. Odae (Apr. 28, 1995. Lee and Kim s.n. EWH); [26-29]: Mt. Odae (May. 10, 1994. Lee and Kim s.n. EWH); [30]: Mt. Odae (Apr. 28, 1995. Lee and Kim s.n. EWH); [31-33]: Mt. Odae (May. 10, 1994. Lee and Kim s.n. EWH); [34]: Mt. Odae (May. 18, 1987. Lee s.n. EWH); [35]: Mt. Dukyu (Apr. 25, 1989. Kim s.n. JNU); Mt. Chukryong (Apr. 23, 1992. Choi. SKK 4); Mt. Kariwang (May, 5, 1989. Lee. SNU 70549); Mt. Whaya (May 5, 1989. Oh. SNU 69330); Mt. Chuweul (May, 10, 1991. Lee. SNU 74953); Mt. Minjuji (May, 12, 1989. Chung. SNU 68879); Mt. Chuksang (May 21, 1992. Lee s.n. EWH)

Isopyrum mandshuricum: Korea-[36-38]: Mt. Whaya (Apr. 17, 1993. Lee. EWH-No.S5); [39-42]: Mt. Whaya (Apr. 16, 1995. Lee, Kim and Cho s.n. EWH); [43-46]: Korea-Mt. Whaya (Apr. 17, 1993. Lee. EWH-No.S5); [47]: Mt. Whaya (Apr. 16, 1995. Lee, Kim and Cho s.n. EWH); [48-53]: Mt. Chunma (Apr. 16, 1994. Lee s.n. EWH); [54]: Mt. Chunma (Apr. 11, 1991. Lee and Yeau. EWH-No.S1); [55]: Mt. Chunma (Apr. 17, 1993. Lee. EWH-No.S3); Mt. Chunma (Apr. 13, 1986. Lee. SNU 60654); Mt. Chuwheul (May, 3, 1987. Kim. SNU 65031); Mt. Yongmun (May 5, 1993. Lee s.n. EWH)

Semiaquilegia adoxoides: Korea-[56-59]: Byunsan (Apr. 1, 1995. Lee and Kim. EWH-No.S15); [60]: Daeheungsa (Apr. 7, 1994. Lee and Kim s.n. EWH); [61-70]: Daeheungsa (Apr. 9, 1994. Lee and Kim s.n. EWH); [71-77]: Daeheungsa71-7 (Apr. 7, 1994. Lee and Kim s.n. EWH); Mt. Baekyang (Apr. 24. 1992. Lee s.n.

SKK); Mt. Chongok (June 3, 1989. Lee and Lee. SKK 3966); Isl. Cheju (Mar. 17, 1994. Park s.n. SKK); Mt. Baekyang (Apr. 24, 1992. Lee. s.n. SKK); Isl. Anmyon (Apr. 24, 1964. SKK 3965); Changsung (May, 12, 1985. Ahn. SNU 72356)

References

- Année (1861) *Enemion raddeanum* Regel. *Bull Soc Nat Moss* 34: 61.
- Bentham G and Hooker JD (1873) *Genera Plantarum* I: 6-8. Reprinted 1965 by Wheldon and Wesley, Ltd. and Verlag J. Cramer, Strechert-Hafner Service Agency, Inc. New York.
- Buchheim G (1964) A. Engler's Syllabus der Pflanzenfamilien In: Melchior H (ed), *Gebrüde Borntraeger*, Berlin, pp 1-135.
- Calder JA and Taylor RL (1963) A new species of *Isopyrum* endemic to the Queen Charlotte Islands of British Columbia and its relation to other species in the genus. *Madrono* 17: 69-76.
- De Candolle AP (1824) *Prodromus Systematis Naturalis regni Vegetabilis*. 1. Paris.
- Drummond JR and Hutchinson J (1920) A revision of *Isopyrum* (Ranunculaceae) and its nearer allies. *Bull Miscel Infor Kew* 5: 145-169.
- Engler A and Prantle A (1891) *Die natürlichen Pflanzenfamilien*. III. 2: 56. Wilhelm Engelmann, Leipzig, p 56.
- Erdtman G (1960) The acetolysis method. A revised description. *Sven Bot Tidskr* 54: 561-564.
- Fu DZ (1990) Phylogenetic considerations on the subfamily Thalictroideae (Ranunculaceae). *Cathaya* 2: 181-190.
- Hill AW (1933) *Index Kewensis Plantarum Phanerogamarum Supplement, Octavum*, Oxford University Press, London, pp 125, 219.
- Hoot SB (1991) Phylogeny of the Ranunculaceae based on epidermal microcharacters and micromorphology. *Syst Bot* 16: 741-755.
- Hoot SB (1995) Phylogeny of the Ranunculaceae based on atpB, rbcL and 18S nuclear ribosomal DNA sequence data. *Plant Syst Evol* 9: 241-251.
- Hsiao PK (1979) *Flora Reipublicae Popularis Sinicae*. Vol 27. Institutum Botanicum Academiae Sinicae, Beijing, pp 466-502.
- Hutchinson J (1923) Contributions towards a phylogenetic classifications of flowering plants. *Bull Miscel Infor Kew No.* 2, 65-89.
- Keener CS (1977) Studies in the Ranunculaceae of the southeastern United States. VI. Miscellaneous genera. *Sida* 7: 1-12.
- Komarov VL (1926) *Semiaquilegia manshurica* Kom. *Not Syst Herb Hort Bot Petrop* 6: 5.
- Komarov VL (1926) *Isopyrum manshuricum* Kom. *Not Syst Herb Hort Bot Petrop* 6: 6.
- Langlet O (1932) *Über Chromosomen Verhältnisse und Systematik der Ranunculaceae*. *Sven Bot Tidskr* 26: 381-400.
- Lee TB (1980) *Illustrated Flora of Korea*. Hyangmunsa, Seoul, pp 358, 367.
- Lee YN (1974) A unrecorded species: *Semiaquilegia mandshurica*. *J Korean Res Inst Better Living, Ewha Womans Univ* 13: 83-86.
- Lee YN (1976) *Illustrated Encyclopedia of Flora and Fauna of Korea*. Vol 18. Flowering Plants. Samwha Publication, Seoul, pp 205-206, 504.
- Lee YN (1996) *Flora of Korea*. Kyohaksa, Seoul, pp 188, 200, 204-205.
- Nakai T (1952) *A Synoptical Sketch of Korean Flora*. The National Science Museum, Tokyo, pp 28-30.
- Ohwi J (1932) *Isopyrum yamasutaum*. *Acta Phytotaxon Geobot* 1: 80.
- Ohwi J (1984) *Flora of Japan*. Smithsonian Institution, Washington DC, pp 454-458.
- Rohlf FJ (1992) *Numerical Taxonomy and Multivariate Analysis*

- System, Version 1.70 (NTSYS-pc). Exeter Software, New York.
- Satake Y, Ohwi J, Kitamura S, Watari S, and Tominari T (1983) Wild Flowers of Japan. Heibonsha Ltd Publication, Tokyo, pp 80-82.
- Tamura M (1962) Taxonomical and phylogenetical consideration of the Ranunculaceae. *Acta Phytotaxon Geobot* 20: 71-81.
- Tamura M (1966) Morphology, ecology and phylogeny of the Ranunculaceae. VI. *Sci Rep Osaka Univ* 15: 13-35.
- Tamura M (1967) Morphology, ecology and phylogeny of the Ranunculaceae. VII. *Sci Rep Osaka Univ* 16: 21-43.
- Tamura M (1968) Morphology, Ecology and Phylogeny of the Ranunculaceae. VIII. *Sci Rep Osaka Univ* 17: 41-56.
- Tamura M (1992) A new classification of the family Ranunculaceae. 3. *Acta Phytotaxon Geobot* 43: 53-58.
- Tamura M and Lauener LA (1968) A revision of *Isopyrum*, *Dichocarpum* and their allies. *Notes Roy Bot Garden Edinb* 28: 267-273.

[Received September 2, 1998; accepted September 24, 1998]