

A taxonomic review of Korean *Asparagales* and *Liliales* (Liliopsida)

Jang, Chang-Gee*, Martin F. Pfosser

(Department of Higher Plant Systematics, Institute of Botany,
Vienna University, Rennweg 14, A-1030 Wien, Austria)

A systematic review for Korean Liliopsida was carried out with *rbcl* and *atpB* sequence data. Congruent phylogenetic trees were obtained from two different data sets. Korean Liliopsida consists of the three orders, *Asparagales*, *Liliales*, and *Dioscoreales sensu* Dahlgren *et al.* Members of *Dioscoreales* were used as an out-group for inferring relationships among *Asparagales* and *Liliales* in the molecular studies. Iridaceae showed close relationship to *Asparagales* both in the *rbcl* and *atpB* sequence trees rather than to *Liliales*. Family Nartheciaceae (previously included within Melanthiaceae *s. lat.*) appeared as a paraphyletic assemblage basal within *Liliales*, but did not show relationships to other orders. Genera of Ruscaceae (previously Convallariaceae) like *Disporum*, *Clintonia*, and *Streptopus* had to be transferred to Colchicaceae, Liliaceae, and Calochortaceae, respectively. A revised list of families for Korean members of Liliopsida is suggested.

Key words: Korean Liliopsida, molecular data, *Asparagales*, *Liliales*

In the traditional taxonomic systems of Bentham and Hooker (1883) and Engler and Prantl (1888), most Liliaceous plants with a superior ovary were placed in a broadly conceived family Liliaceae split into many tribes. Cronquist (1981) used a more traditional approach in his circumscription of monocot families and recognized 15 families within *Liliales*. Because their family concepts were very narrow, Dahlgren *et al.* (1985) classified the Liliaceous plants into 27

*Corresponding author: Phone: +43-1-4277 54141, Fax: +43-1-4277 9541,
e-mail: polygonatum@hanmail.net

(접수: 2002년 11월 10일, 심사완료: 2002년 11월 19일)

different families comprising five orders.

The broad definition of Liliopsida by Dahlgren *et al.*, (1985) who largely followed the concept of Huber (1969), divided this largest and most diverse super-order of monocotyledons into five orders: *Dioscoreales*, *Asparagales*, *Melanthiales*, *Burmanniiales* and *Liliales*. Three orders of them, *Dioscoreales*, *Asparagales*, and *Liliales* were recognized in Korea.

The order *Dioscoreales* shows a number of features believed to be ancient and several of them associate this order with dicotyledoneous families. Therefore, this order could easily be discriminated from *Asparagales* and *Liliales*. The order *Asparagales* represents a monophyletic group characterized by a specialized seed coat containing phytomelan in most of its capsule-fruited taxa (Dahlgren *et al.*, 1985). In addition to the phytomelaneous seeds, Dahlgren *et al.* (1985) listed 16 characters that differed between *Asparagales* and *Liliales*, although most of them did not occur in all taxa and several of them were plesiomorphic. Most of these characters are micromorphological characters, and thus no single field character was known that distinguishes the two orders with certainty. The largest of these orders is the order *Asparagales* and comprises 33 families (Kubitzki 1998). Dahlgren *et al.* (1985) used narrow family circumscriptions that were more likely to yield monophyletic families.

Recent DNA sequence data (Chase *et al.*, 1995) in combination with non-molecular studies (Tamura, 1995; Chase *et al.*, 1996; Fay and Chase, 1996; Rudall and Chase, 1996) have improved our understanding of family boundaries and affinities within Liliopsida. The most important synapomorphy for this order, first used by Huber (1969) as a unifying character, was the characteristic black seeds caused by phytomelan incrustation of the seed coat in most of the capsular and some berry-fruited taxa. The taxa now included in this order were relatively little known at the time of Krause (1930), who placed them into a broadly defined family Liliaceae.

Schlittler (1953) brought into focus the interesting phenomenon of articulation of flowers on the pedicels, which among monocots was concentrated within *Asparagales*. Both molecular and morphological data indicated that *Asparagales* comprises a paraphyletic lower asparagoid clade including early-branching families (including Orchidaceae, Iridaceae, and Tecophilaeaceae), and a higher asparagoid clade (including Agavaceae, Alliaceae, and Ruscaceae [Convallariaceae]). Simultaneous microsporogenesis and inferior ovaries were regarded as characteristic for lower asparagoids, whereas higher asparagoids

have successive microsporogenesis (Rudall *et al.*, 1997) and generally superior ovaries. The boundaries between *Asparagales* and *Liliales* are difficult to define using morphological data alone, as several characters are shared between some lilioids and lower asparagoids (Rudall *et al.*, 2000).

Although monocots usually have successive microsporogenesis, simultaneous microsporogenesis with inferior ovaries are characteristic of lower asparagoids with some exceptions. Otherwise, all higher asparagoids show successive microsporogenesis and generally superior ovaries (Rudall *et al.*, 1997).

Because traditional taxonomic systems (Krause 1930, Cronquist 1981) were applied for the classification of Korean Liliopsida, almost all Korean Liliopsida were placed into only a few families, especially into a broadly defined family Liliaceae. Although several systematic studies were performed at the generic level (Lee, 1985; Chung and Chung, 1988; Yu *et al.*, 1981; Kim and Lee, 1990; Kim and Lee, 1991; Tae, 1995; Sim, 1988; Jang, 1998), studies at higher level taxonomy for Korean monocots are still scarce. Therefore, the application of a reasonable system for classification of Korean Liliopsida is still strongly required.

In the present study we used molecular data of the chloroplast *rbcL* and *atpB* genes to examine the relationship among families variously placed in the systematic treatments cited above. Although the Korean flora contains only a few families and genera of Liliopsida, and, therefore, the phylogenies are partly inflated by limited sampling, there is a necessity for arrangement of families and their generic members to facilitate future studies at the genus level.

Phylogenetic relationships among a wide array of seed plants have been intensively studied using the large subunit of ribulose-1,5-bisphosphate carboxylase/oxygenase (*rbcL*) including a number of relevant lilioid taxa (Chase *et al.*, 1993; 1995; Duvall *et al.*, 1993). Later, the *atpB* plastid gene was used for phylogenetic studies among monocot taxa. Both genes were regarded as strong tools to reveal relationships within Liliopsida (Fay *et al.*, 2000).

In this study, we will address the following topics: 1) the applicability of Kubitzki's revised classification (1998) based on Dahlgren *et al.* (1995) for the taxonomy of Korean Liliopsida. 2) evaluation of relationships among Korean Liliopsida by conducting analyses of nucleotide sequence data from 18 families containing common members of the Korean monocot flora. 3) confirmation of the transfer of several genera like *Disporum*, *Clintonia*, and *Streptopus* from their affinity to Convallariaceae (Ruscaceae) to other families in *Liliales*. 4) elucidation of the position of Iridaceae and Nartheciaceae (previously included

within Melanthiaceae s. lat.) in the classification of Korean Liliopsida.

Material and Methods

We studied 18 families containing common members of the Korean flora using *rbcL* and *atpB* sequence data in phylogenetic analyses.

Family Dioscoreaceae was designated as outgroup for our molecular analyses. All data for plastid DNA sequences were taken from the EMBL gene bank (for accession numbers refer to Table 1). Sequence manipulations were performed on a Digital Alpha 1000A 5/400 server under the operating system Digital Unix V.4.0D. DNA sequences were pre-aligned using the PileUp program of the GCG software package (Genetic Computer Group, 1994). Final alignment of DNA sequences was done visually. The sequences have been trimmed on both ends to exclude ambiguous positions in close proximity to the sequencing primers. Phylogenetic analyses using the maximum parsimony (MP) method were performed with the computer program PAUP* version 4.0b10 (Swofford, 2000). MP analyses were performed with and without successive character weighting (rescaled consistency index) until tree lengths remained the same in two successive rounds. Most parsimonious trees were obtained by 1000 replicates of random sequence addition using tree bisection-reconnection (TBR) branch swapping under the Fitch criterion (Fitch, 1971). Ten thousand fast bootstrap replicates (Felsenstein, 1985) were used to assess confidence limits for the resulting tree topologies. Tree manipulations were performed using MacClade version 3.06 (Maddison and Maddison, 1993)

Results

Phylogenetic analysis of *rbcL* data: Maximum parsimony analysis of *rbcL* data yielded thirteen different strict consensus trees with a weighted tree length of 336.51612, a consistency index (CI) of 0.797, a retention index (RI) of 0.904, a rescaled consistency index (RC) of 0.720, and a homoplasy index (HI) of 0.203. Differences in tree topologies among the trees were restricted to minor rearrangements within family Ruscaceae but did not change relationships among families and orders. Since tree topologies remained similar both in the unweighted and successively weighted trees, only successively weighted trees are shown, because bootstrap values tended to be higher in those trees. One of

Table 1. Taxa Examined for molecular analysis.

Order/Family	Cronquist's System	Reference for System	Species	<i>rbcl</i>	<i>atpB</i>
Dioscoreales					
Dioscoreaceae	Dioscoreaceae	Dahlgren <i>et al.</i> 1985	<i>Dioscorea bulbifera</i>		AF187059
	* <i>Dioscorea</i>		<i>Dioscorea japonica</i>	AF307457	
			<i>Dioscorea tenuipes</i>	AB017340	
Liliales					
Liliaceae	Liliaceae	Huber 1969	<i>Lilium superbum</i>	AB034926	AF209618
	* <i>Lilium</i>	Dahlgren <i>et al.</i> 1985	<i>Lilium japonicum</i>		AB034921
	* <i>Erythronium</i>	Tamura 1995	<i>Erythronium japonicum</i>	D28156	
	* <i>Tulipa</i>		<i>Tulipa kolpakowskiana</i>		AJ235633
			<i>Tulipa turkestanica</i>	AB037378	
	* <i>Fritillaria</i>		<i>Fritillaria koidzumiana</i>	AB034939	
	* <i>Lloydia</i>		<i>Lloydia serotina</i>	AJ235523	
	* <i>Clintonia</i>		<i>Clintonia udensis</i>	AB034750	
			<i>Clintonia borealis</i>	AB056856	
		* <i>Gagea</i>		<i>Gagea lutea</i>	AB034752
Melanthiaceae	* <i>Veratrum</i>	Tamura 1995	<i>Veratrum viride</i>		AJ235638
		Chase <i>et al.</i> 1995	<i>Veratrum maackii</i>	AB018849	
	* <i>Heloniopsis</i>		<i>Heloniopsis orientalis</i>	AJ417894	AJ417583
Nartheciaceae	* <i>Aletris</i>	Ambrose 1980	<i>Aletris farinosa</i>		AF308040
	* <i>Metanarthecium</i>		<i>Metanarthecium luteo-viride</i>		AF308041
	* <i>Tofieldia</i>		<i>Tofieldia calyculata</i>		AJ235627
Calochortaceae	* <i>Tricyrtis</i>	Tamura 1995	<i>Tricyrtis latifolia</i>		AJ235630
		Chase <i>et al.</i> 1993, 1995	<i>Tricyrtis macrantha</i>	AB034749	
*					
	<i>Streptopus</i>		<i>Streptopus amplexifolius</i>	AF275992	
			<i>Calochortus albus</i>	AF275983	
Trilliaceae	* <i>Trillium</i>	Dahlgren <i>et al.</i> 1985	<i>Trillium erectum</i>		AF209692
		Chase <i>et al.</i> 1995	<i>Trillium ovatum</i>	AB018840	
*					
	<i>Paris</i>		<i>Paris tetraphylla</i>	D28159	AJ417584
Colchicaceae		Shinwari <i>et al.</i> 1994	<i>Colchicum autumnale</i>	AF168895	
		Chase <i>et al.</i> 1995	<i>Uvularia sessilifolia</i>		AB009948
	* <i>Disporum</i>		<i>Disporum sessile</i>	D17376	
Smilacaceae	* <i>Smilax</i>	Cronquist 1981	<i>Smilax glauca</i>	AF206822	AF209677
Asparagales					
Hostaceae	* <i>Hosta</i>	Rudall <i>et al.</i> 1997	<i>Hosta rectifolia</i>	L10253	
Hemerocallidaceae	* <i>Hemerocallis</i>	Chase <i>et al.</i> 1993	<i>Hemerocallis</i>		AF168923
			<i>lilioasphodelus</i>		
		Rudall <i>et al.</i> 1996	<i>Hemerocallis fulva</i>	L05036	
Alliaceae	* <i>Allium</i>	Dahlgren <i>et al.</i> 1985	<i>Allium altaicum</i>	AF206731	AF209525
			<i>Allium cepa</i>	AF479574	

Table 1. Continued.

Order/Family	Cronquist's System	Reference for System	Species	<i>rbcL</i>	<i>atpB</i>	
Hyacinthaceae	* <i>Hyacinthus</i>	Speta 1980	<i>Hyacinthus orientalis</i>	AF116995	AF168925	
			<i>Ornithogalum caudatum</i>		AF168935	
	* <i>Scilla</i>		<i>Scilla scilloides</i>	D28161		
Asparagaceae	* <i>Asparagus</i>	Chase <i>et al.</i> 1995	<i>Asparagus officinalis</i>		AJ235400	
			<i>Asparagus cochinchinensis</i>	AB029849		
Ruscaceae	* <i>Aspidistra</i>	Dahlgren <i>et al.</i> 1985	<i>Aspidistra elatior</i>		AJ417575	
		Rudall <i>et al.</i> 2000	<i>Tupistra albiflora</i>	AB029837		
			<i>Tricalistra ochreatea</i>	AB029839		
	* <i>Rohdea</i>		<i>Rohdea japonica</i>	AB029836		
			<i>Campylandra sp.</i>	AB029835		
	* <i>Convallaria</i>		<i>Convallaria majalis</i>	D28334	AF168897	
			<i>Reineckea carnea</i>	AB029834		
	* <i>Liriope</i>		<i>Liriope muscari</i>	AF168926		
			<i>Ophiopogon japonicus</i>	AB029841		
	* <i>Ophiopogon</i>	* <i>Smilacina</i>		<i>Smilacina racemosa</i>		AF168945
			<i>Smilacina hondoensis</i>	D17380		
		<i>Calibanus hookeri</i>		AJ417576		
* <i>Polygonatum</i>			<i>Polygonatum hookeri</i>		AJ417578	
			<i>Polygonatum humile</i>	AB029828		
			<i>Polygonatum involucreatum</i>	AB029829		
			<i>Heteropolygonatum pendulum</i>	AB029831		
			<i>Disporopsis longifolia</i>	AB029833		
			<i>Peliosanthes grandifolia</i>	AB029845		
		Anemarrhenaceae	Haemodoraceae	Chase <i>et al.</i> 1995	<i>Anemarrhena</i>	
	* <i>Anemarrhena</i>			<i>asphodeloides</i>		
Agavaceae	Agavaceae	Bogler & Simpson 1995	<i>Agave ghiesbreghtii</i>		AF209521	
	* <i>Agave</i>					
Amaryllidaceae	Amaryllidaceae	Meerow <i>et al.</i> 2000	<i>Hippeastrum sp.</i>		AF168924	
	* <i>Hippeastrum</i>		<i>Hippeastrum papilio</i>	AF206776		
			<i>Hippeastrum papilio</i>		AF209598	
	* <i>Crinum</i>		<i>Crinum yemenense</i>	AF116951		
	* <i>Clivia</i>		<i>Clivia nobilis</i>	AF116950	AF209566	
	* <i>Lycoris</i>		<i>Lycoris sanguinea</i>	AB034753		
	* <i>Narcissus</i>		<i>Narcissus elegans</i>	AF116972		
Iridaceae	Iridaceae	Dahlgren <i>et al.</i> 1985	<i>Iris germanica</i>	L05037		
	* <i>Iris</i>		<i>Iris forrestii</i>	AJ307083		
	* <i>Gladiolus</i>		<i>Gladiolus buckerveldii</i>	AF206772	AF209592	

*genera present in Korea (*Chionographis*, *Zygadenus*, *Maianthemum*, *Yucca*, *Zephyranthes*, *Sisyrinchium*, and *Belamcanda* were not analysed).

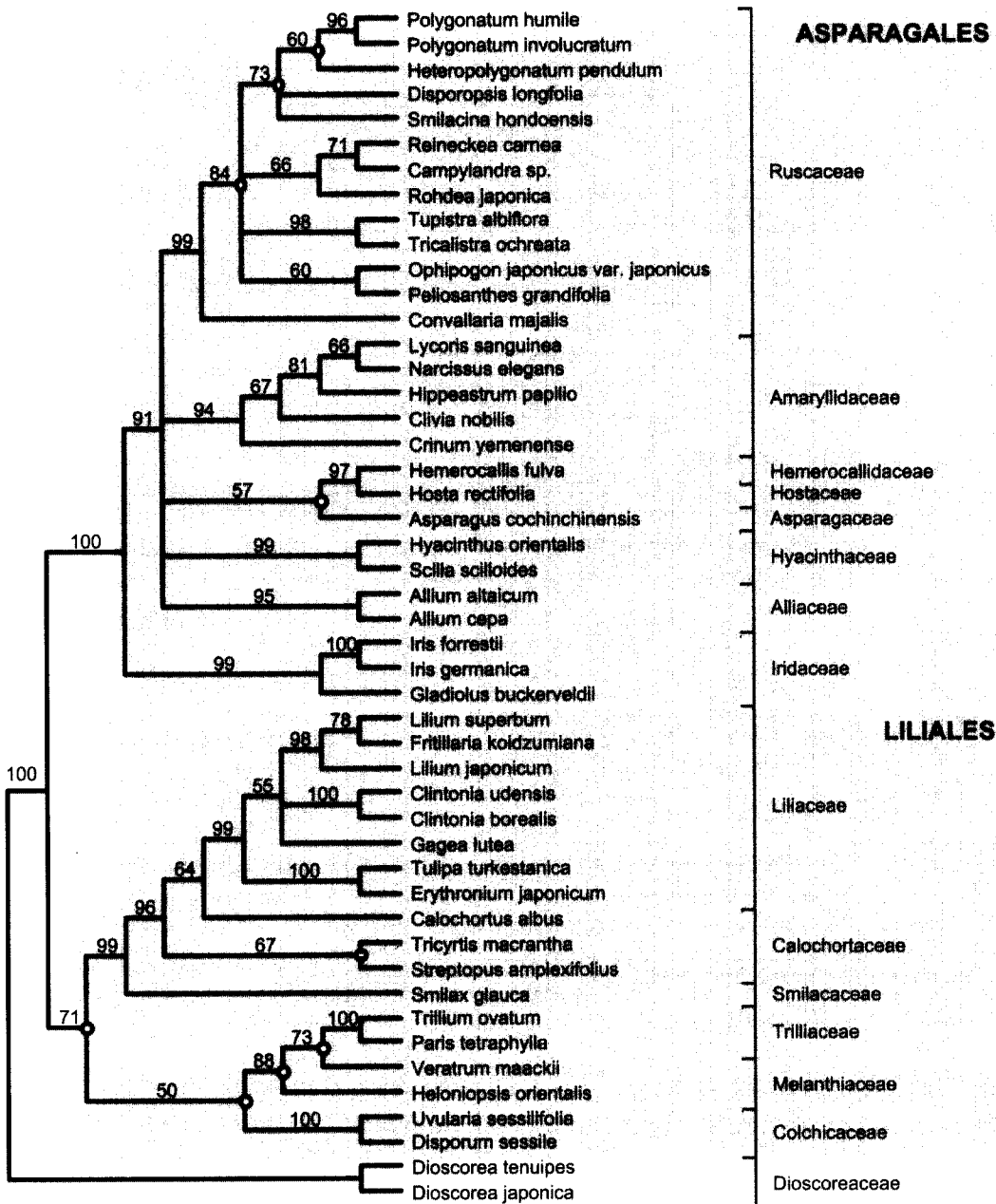


Fig. 1. One of thirteen equally most parsimonious strict consensus trees based on cladistic analysis of *rbcl* data for representative taxa of Liliopsida. Bootstrap values >50% after successive character weighting are indicated above branches. Nodes not present in the unweighted trees are indicated by open circles.

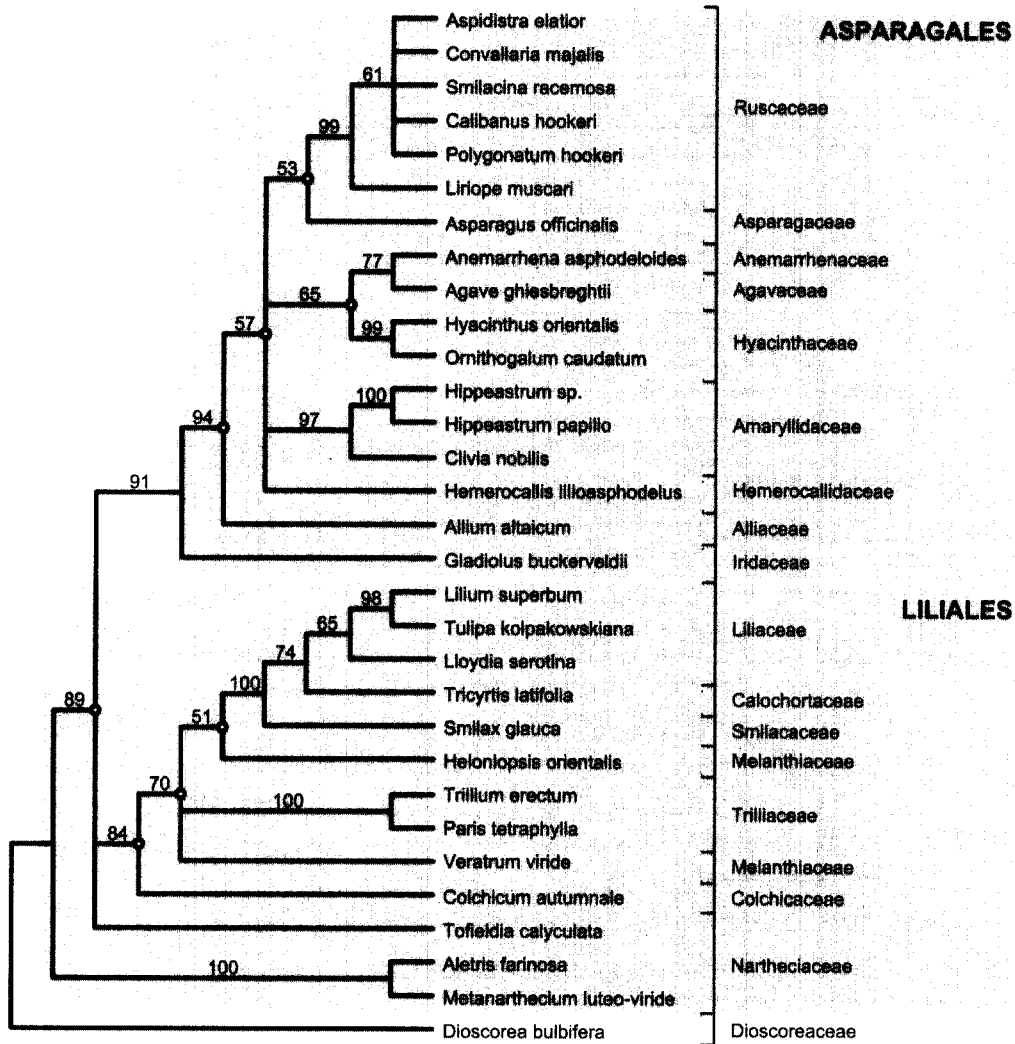


Fig. 2. One of three equally most parsimonious strict consensus trees based on cladistic analysis of *atpB* data for representative taxa of Liliopsida. Bootstrap values >50% after successive character weighting are indicated above branches. Nodes not present in the unweighted trees are indicated by open circles.

the equally parsimonious trees is shown in Fig. 1. Nodes not present in the unweighted trees are indicated by open circles.

In the *rbcl* tree the order *Asparagales* formed a highly supported monophyletic

group with the inclusion of Iridaceae (100% bootstrap support) and appeared to be well separated from *Liliales*. Within *Asparagales*, family Ruscaceae was monophyletic (99%). The genera *Disporum*, *Clintonia*, and *Streptopus* (previously included within Convallariaceae), however, were not included within *Asparagales* but formed a clade with members of *Liliales* (Colchicaceae, Liliaceae, and Calochortaceae, respectively).

Phylogenetic analysis of *atpB* data: Maximum parsimony analysis of *atpB* data yielded three strict consensus trees with a weighted tree length of 300.14030, a consistency index (CI) of 0.828, a retention index (RI) of 0.834, a rescaled consistency index (RC) of 0.691, and a homoplasy index (HI) of 0.172. One of the equally most parsimonious trees is shown in Fig. 2. Like in the *rbcL* analysis, only minor intra-familial differences in topologies were encountered between weighted and unweighted trees in the *atpB* analysis.

Both *Asparagales* (91% bootstrap support value) and core *Liliales* (84% bootstrap support) yielded clearly separated clades. The genera *Tofieldia*, *Aletris* and *Metanartheicum* (Nartheciaceae) formed a paraphyletic assemblage at the base of *Liliales*. Within *Asparagales*, Ruscaceae appeared as a well-supported monophyletic group with a high bootstrap value (99%). The genus *Gladiolus* (family Iridaceae) nested within *Asparagales* (91% bootstrap support).

Discussion

Most recent treatments (Dahlgren *et al.* 1985; Takhtajan 1987; Thorne 1992; Kubitzki, 1998) tended to recognize more narrowly defined families. The classification into Liliopsida (instead of Liliflorae sensu Dahlgren *et al.* (1985); Thorne, 1992) represented an improvement over previous systems because a wide range of characters from many different types of data was considered, whereas earlier concepts often were based on single definitive characters. The broad classifications of Krause (1930), Hutchinson (1934) and Cronquist (1981) were not supported from our results, whereas that of Dahlgren *et al.* (1985), who recognized numerous smaller families, was reflected in our phylogenetic analyses.

The usage of *Acorus* (Acoraceae) as outgroup for Korean Liliopsida had been considered in our study, following the suggestion of Chase *et al.* (1995), but this result gave little resolution for the classification of Korean Liliopsida (data not shown). This might be caused by several big gaps in sampling of taxa for

analysis at higher taxonomical levels. To use family Dioscoreaceae as an out-group, however, yielded satisfactory resolution for this study.

Although taxon sampling was not the same for both analyses, the tree topologies obtained were highly congruent. All members of *Liliales* and *Asparagales* formed clearly defined clades and most families in the sense of Kubitzki (1998) yielded monophyletic groups. This means that Kubitzki's system, which is characterized by narrow family concepts, should be applicable for the classification of Korean Liliopsida, too.

The results of our cpDNA study provided strong evidence that there were two major lineages in this group of Korean taxa. One lineage contained all *Asparagales* sensu Dahlgren *et al.* (1985) plus Iridaceae. Iridaceae were included by Dahlgren *et al.* (1985) on the basis of their extrorse anthers, non-phytomelanous seeds, mottled tepals, and perigonal nectaries within *Liliales*, close to Colchicaceae. The presence of perigonal nectaries was, however, known to be the derived state in the family, whereas septal nectaries is the ancestral state. Mottled tepals are also derived in Iridaceae and helobial endosperm development appears to be characteristic for lower Iridaceae. Thus the placing on Iridaceae in a narrowly circumscribed *Liliales* appears to have little support. Molecular gene sequence similarities also support the latter relationship (Rudall *et al.* 2000). DNA sequences from the chloroplast gene *rbcL* placed Iridaceae close to, but outside the core taxa of *Asparagales*, which have phytomelan-in-crustured seeds. Despite the absence of phytomelaneous seeds, assignment of Iridaceae to *Asparagales* must be given serious consideration even on morphological grounds, although overall morphology of Iridaceae appears superficially more similar to that of *Liliales* than that of *Asparagales* (Huber, 1969; Dahlgren *et al.*, 1985).

The other major lineage consists of members from *Liliales* sensu Dahlgren *et al.* (1985) with the inclusion of *Disporum*, *Clintonia*, and *Streptopus*. In the cpDNA sequence data, family Nartheciaceae appeared paraphyletic and basal to *Asparagales* and *Liliales*. Melanthiaceae *s. lat.* was suggested as a different order (Dahlgren *et al.*, 1985) and a sister group for the remaining monocotyledons (Rudall *et al.*, 2000). Some genera formerly included in Melanthiaceae *s. lat.*, such as *Tofieldia*, *Narthecium* and *Aletris*, were shown to belong to other orders. This reclassification was largely based on the analysis of molecular data from *rbcL* sequences but was justified by morphological characters (Rudall *et al.*, 2000). Melanthiaceae *s. lat.* share common characters with *Asparagales* like the

tepals having perigonal nectaries. Tamura (1995) suggested a separation of some genera from Melanthiaceae *s. lat.* into Nartheciaceae which have large chromosomes in contrast to those of the core Melanthiaceae. Our data strongly support Tamuras (1995) suggestion and agree with Kubitzkis system that classifies members of Melanthiaceae *s. lat.* into two separate families, Melanthiaceae *s. str.* and Nartheciaceae. Whereas Melanthiaceae *s. str.* are clearly included within Liliales, no support for inclusion of Nartheciaceae within *Liliales* or *Asparagales* is found in the molecular analyses. This family lacks features typical for either *Asparagales* or *Liliales*. It differs from *Asparagales* in that the seeds are not phytomelaniferous, the tepals are inconspicuous, the stylodial branches are generally separate and the embryos are small. Unlike in *Liliales*, the endosperm formation is helobial in Nartheciaceae (Melanthiaceae *s. lat.*) and septal nectaries may be lacking. The tepals are less conspicuous and rarely spotted (characteristic for *Liliales*) and raphides are generally present (Dahlgren and Clifford, 1982).

According to our *atpB* sequence analysis, genus *Tofieldia* seems to be only distantly related to the other two genera *Aletris* and *Metanarthecium*. Therefore, Nartheciaceae could be subdivided into the two subfamilies Tofieldioideae and Narthecioideae as already suggested (Conran and Tamura, 1998). Ambrose (1980) undertook a numerical analysis of morphological characters of Melanthiaceae *s. lat.* and revealed three main clusters: (1) the *Tofieldia* group, (2) the *Narthecium* group, and (3) the *Melanthium* group. Chase *et al.* (1995) recognised similar groupings based on a parsimony analysis of *rbcl* sequences: (1) *Pleea* and *Tofieldia*, (2) *Aletris* (including *Metanarthecium*) and (3) the present Melanthiaceae *s. str.* including genera such as *Heloniopsis*, *Zigadenus*, and *Verastrum*. Nartheciaceae in the present circumscription contain group 1 and group 2 of Ambrose (1980) and Chase *et al.* (1995); group 1 corresponds to subfamily Tofieldioideae and group 2 to subfamily Narthecioideae in the classification of Conran and Tamura (1998).

One of the most consistent synapomorphies for *Liliales* is the presence of mainly three-traced tepals. It effectively distinguishes the net-veined lilioid taxa (e.g. *Disporum*, *Clintonia*, and *Streptopus*) from the net-veined asparagoids (e.g. *Convallaria*, *Polygonatum*, *Maianthemum*, and *Smilacina*), which have generally one-traced tepals (Vaikos *et al.*, 1989). Bjornstad (1970) pointed out that *Disporum* and *Clintonia* (previously referred to as members of Convallariaceae) show better agreement with Uvulariaceae, Colchiaceae, and Liliaceae. Dahlgren

et al. (1985) and Conran (1989) removed *Disporum*, *Clintonia*, and *Streptopus* from Convallariaceae and treated these genera as members of Colchicaceae, Liliaceae, and Calochortaceae, respectively. Although the *rbcl* studies of Shinwari *et al.* (1994) focused only on the berry-fruited taxa of Polygonatae including *Disporum*, *Clintonia*, and *Streptopus*, this transfer is supported by karyological data (Tamura, 1995) and molecular evidence (Chase *et al.*, 1995; Wu *et al.*, 2000).

Conclusions

The data suggest that the concept of Liliopsida as proposed by Cronquist (1981) is less accurate than that proposed by Dahlgren *et al.* (1985). According to this result, the revised Kubitzkis system based on Dahlgren *et al.* should be applied for the classification of Korean Liliopsida. Although the sampling of Korean taxa should be increased in future studies, we suggest the following list of families for Korean Liliopsida.

Liliales; Liliaceae (including *Lilium*, *Erythronium*, *Tulipa*, *Fritillaria*, *Lloydia*, *Clintonia*, and *Gagea*), Melanthiaceae *s. str.* (including *Veratrum*, *Heloniopsis*, *Zygadenus*, *Chionographis*), Nartheciaceae (Subfam. Narthecioideae (*Aletris*, *Metanarthecium*), Subfam. Tofieldioideae (*Tofieldia*), Calochortaceae (including *Tricyrtis*, *Streptopus*), Trilliaceae (including *Trillium*, *Paris*), Colchicaceae (including *Disporum*), Smilacaceae (including *Smilax*).

Asparagales; Hostaceae (including *Hosta*), Hemerocallidaceae (including *Hemerocallis*), Alliaceae (including *Allium*), Hyacinthaceae (including *Hyacinthus*, *Scilla*), Asparagaceae (including *Asparagus*), Ruscaceae (including *Aspidistra*, *Rohdea*, *Convallaria*, *Liriope*, *Ophiopogon*, *Smilacina*, *Maianthemum*, *Polygonatum*), Anemarrhenaceae (including *Anemarrhena*), Agavaceae (including *Agave*, *Yucca*), Amaryllidaceae (including *Zephyranthes*, *Hippeastrum*, *Crinum*, *Clivia*, *Gladiolus*, *Lycoris*, *Narcissus*), Iridaceae (including *Iris*, *Sisyrinchium*, *Belamcanda*, *Gladiolus*).

Acknowledgement

This research was supported by a grant (code PF001302-00) from Plant Diversity Research Center of 21st Century Frontier Research Program funded by Ministry of Science and Technology of Korean government.

Literature Cited

- Ambrose, J. D. 1980. A re-vision of the Melanthioideae (Liliaceae) using numerical analyses. *In* Brickell, C. D., Culter, D. F., Gregory, M. (eds.) *Petaloid monocotyledons*, London: Academic Press. (Linnean Society Symposium Series Vol. 8). Pp. 65-81.
- Bentham, G. and J. D. Hooker. 1883. Liliaceae. *In* *Genera Plantarum*. Bentham, G. and J. D. Hooker (eds.) London, L. Reeve Pp. 748-836.
- Bjornstad, I. N. 1970. Comparative embryology of Asparagoideae Polygonatae, Liliaceae. *Nytt. Mag. Bot.* 17: 169-207.
- Chase, M. W., Duvall, M. R., Hills, H. G., Conran, J. G., Cox, A. V., Eguiarte, L. E., Hartwell, J., Fay, M. F., Caddick, L. R., Cameron, K. M., Hoot, S. 1995. Molecular Phylogenetics of Liliaceae. *In* *Monocotyledons: Systematics and Evolution*. Royal Botanic Gardens, Rudall, P. J., Cribb, P. J., Cutler, D. F., Humphries, C. J. (eds.) Kew, London, Pp. 109-137.
- Chase, M. W., P. J. Rudall and J. G. Conran. 1996. New circumscriptions and a new family of asparagoid lilies: genera formerly included in Anthericaceae. *Kew Bulletin* 51: 667-680.
- Chase, M. W., Soltis, D., Olmstead, R. G., Morgan, D., Les, D. H., Mishler, B., Duvall, M. R., Price, R. A., Hills, H. G., Qui, Y-L., Kron, K. A., Rettig, J. H., Conti, E., Palmer, J. D., Manhart, J. R., Systma, K. J., Michael, H. J., Kress, W. J., Karol, K. G., Clark, W. D., Hedren, M., Gaut, B. S., Jansen, R. K., Kim, K-J., Wimpee, C. F., Smith, J. F., Fumier, G. R. Straus, S. H., Xiang, Q-Y., Plunkett, G. M., Soltis, P. S., Swensen, S. M., Williams, S. E., Gadek, P. A., Quinn, C. J., Equiarte, L., Goldenberg, E., Leam, G. H., Graham, S. W., Barrett S. C. H., Dayanandan, S. and V. A. Albert. 1993. Phylogenetics of seed plants: an analysis of nucleotide sequence from the plastid gene *rbcL*. *Ann. Missouri Bot. Gard.* 80: 528-580.
- Chung, Y. C. and Y. H. Chung. 1988. A taxonomic study of the genus *Hosta* in Korea. *Kor. J. Pl. Tax.* 18: 161-172. (in Korean)
- Conran, J. G. 1989. Cladistic analysis of some net-veined Liliiflorae. *Pl. Syst. Evol.* 168: 123-141.
- Cronquist, A. 1981. *An Integrated System of Classification of Flowering Plants*. Columbia University Press. New York. Pp. 1262.
- Dahlgren, R. M. T. and H. T. Clifford. 1982. *The Monocotyledons: A Comparative Study*. Academic Press, London. Pp. 378.

- Dahlgren, R. M. T., Clifford, H. T. and Yeo, P. F. 1985. The Families of the Monocotyledons. Springer-Verlag, Berlin. Pp. 520.
- Duvall, M. R., Clegg, M. T. Chase, M. W., Clark, W. D., Kress, W. J., Hills, H. G., Equiarte, L. E., Smith, J. F., Gaut, B. S., Zimmer, E. A. and G. H. Learn. 1993. Phylogenetic hypotheses for the monocotyledons constructed from *rbcL* sequence data. Ann. Missouri Bot. Gard. 80:607-619.
- Engler, A. and K. Frantl. 1888. Die natürlichen Pflanzenfamilien Teil 2, Abteil 5. Leipzig.
- Fay, M. F., Rudall, P. J., Sullivans, S., Stobark, K. L., De Bruijn, A. Y., Qamaaruz-zaman, F., Hong, W.-P., Hahn, W. J., Conran, J. G., Chase, M. W. 2000. Phylogenetic studies of *Asparagales* based on four plastid DNA regions. In Monocots-Systematics and Evolution. Wilson, K. L., Morrison, D. (eds.) CSIRO, Melbourne, Pp. 360-371.
- Felsenstein, J. 1985. Confidence limits on phylogenies: an approach using the bootstrap. Evolution 39:783-791.
- Fitch, W. M. 1971. Toward defining the course of evolution: minimum change for a specific tree topology. Syst. Zool. 20:406-416.
- Genetics Computer Group. 1994. Program manual for the Wisconsin package, Version 8.
- Huber, H. 1969. Die Samenmerkmale und Verwandtschaftsverhältnisse der Liliifloren. Mitteilungen der Botanischen Staatssammlung München 8:219-538.
- Hutchinson, J. 1934. The Families of Flowering Plants. Vol. II. Monocotyledons. Macmillan, London. Pp. 243.
- Jang, C. G. 1998. A systematic study of the genus *Polygonatum* (Liliaceae): with a special reference to Korean species. Ph. D. dissertation, Korea University Seoul. Pp. 458 (in Korean with English abstract).
- Kim, M. and S. Lee. 1991. A taxonomical study of the Korean *Lycoris* (Amaryllidaceae). Kor. J. Pl. Tax. 21:123-139. (in Korean)
- Kim, Y. S. and W. B. Lee. 1990. A study of morphological characters on the genus *Lilium* L. in Korea. Kor. J. Pl. Tax. 20:165-178. (in Korean)
- Krause, K. 1930. Liliaceae. In Die natürlichen Pflanzenfamilien 15a, Engler, A. and K. Prantl (eds.). Leipzig. Engelman. Pp. 227-386.
- Kubitzki, K. 1998. The Families and Genera of Vascular Plants: Flowering Plants Monocotyledons. Vol. 3. Pp 478. Springer-Verlag, Berlin, Heidelberg.
- Lee, N. S. 1985. A taxonomic study of Korean *Veratrum*. Kor. J. Pl. Tax. 15:

49-65. (in Korean)

- Maddison, W. P. and D. R. Maddison. 1992. *MacClade: Analysis of Phylogeny and Character Evolution*. Version 3.0. Sinauer.
- Rudall, P. J. and M. W. Chase. 1996. Systematics of Xanthorrhoeaceae *sensu lato*: evidence for polyphyly. *Telopia* 6: 629-647.
- Rudall, P. J., Furness, C. A., Chase, M. W., Fay, M. F. 1997. Microsporogenesis and pollen sulcus type in *Asparagales* (Lilianaes). *Canad. J. Bot.* 75: 408-430.
- Rudall, P. J., Conran J. G. and M. W. Chase. 2000. Systematics of Ruscaceae/Convallariaceae: a combined morphological and molecular investigation. *Bot. J. Linn. Soc.* 34: 73-92.
- Schlittler, J. 1953. Blütenartikulation und Phyllokladien der Liliaceae organphylogenetisch betrachtet. I. Die BluPhyllokladien der Asparageen als echte Blätter. *Feddes Report.* 55: 154-206; 206-258.
- Shinwari, Z. K., H. Kato, R. Terauchi, S. Kawano. 1994. Phylogenetic relationships among genera in the Liliaceae-Asparagoideae-Polygonatae s. l. inferred from *rbcl* gene sequence data. *Pl. Syst. Evol.* 192: 263-277.
- Sim, J. K. 1988. A Taxonomic study on Iridaceae in Korea. Ph D. thesis, Korea Univ., Seoul (in Korean with English abstract).
- Swofford, D. L. 2000. PAUP* Phylogenetic analysis using parsimony and other methods, vers. 4. Sinauer Associates, Sunderland, Massachusetts.
- Tae, K. H. 1995. A taxonomic study on the genus *Lycoris*. Ph D. dissertation, Hannam Univ., Taejeon (in Korean with English abstract).
- Takhtajan, A. 1987. *Systema Magnoliophytorum*. Nauka, Leningrad. Pp. 439.
- Takhtajan, A. 1997. *Diversity and Classification of Flowering Plants*. Columbia Univ. Press, New York.
- Tamura, M. N. 1995. A karyological review of the orders *Asparagales* and *Liliales* (Monocotyledonae). *Feddes Report.* 106: 83-111.
- Thorne, R. T. 1992. Classification and geography of the flowering plants. *Bot. Rev.* 58: 225-348.
- Vaikos, N. P., Markandeya, S. K., and Pai R. M. 1989. The floral anatomy of the Liliaceae. The tribe Polygonatae. *In Plant Science Research in India*. M. L. Trivedi, B. S. Gill and S. S. Saini (eds.) Today and Tomorrows Printers and Publishers, New Delhi. Pp. 697-705.
- Wu, S. A., H. L. Hu, J. Yang, G. Y. Lao, R. L. You, Ge S. and Zhong Y. 2000. Molecular systematic studies on the tribe Polygonatae (s. l.) in China based on RFLPs data of PCR-amplified chloroplast DNA fragments. *Acta*

Phytotax. Sin. 38:97-110.

Yu, S. O., S. Lee and W. T. Lee. 1981. A taxonomic study of the *Allium* Species in Korea. Kor. J. Pl. Tax. 11:21-41 (in Korean).

한국산 비짜루목 및 백합목(백합강)에 대한 분류학적 재검토

장 창 기, Martin F. Pfosser
(비엔나대학교 식물학연구소)

적 요

분자생물학적 자료에 의한 한국산 백합강 식물에 대한 분류학적 재검토를 시도하였다. 2가지의 다른 자료, 즉 엽록체 DNA인 *rbcL* 및 *atpB* sequence 자료분석에서 대체적으로 일치하는 계통수를 얻었다. 즉, 한국산 백합강은 Dahlgren 등의 분류체계에 의한 비짜루목, 백합목, 마목의 3목으로 구분되었다. 이중 비짜루목과 백합목의 유연관계를 추론하는 분자생물학적 연구에서 마목의 분류군이 군외분류군으로 사용되었다. 두 엽록체 DNA인 *rbcL* 및 *atpB* sequence 분석에서 붓꽃과는 백합과 보다는 비짜루과에 더 가까운 유연관계를 보여주었다. 그러나, 넓은 의미의 Narthecaceae (종전의 Melanthiaceae [국명부재]에 속한 분류군)는 비짜루목이나 백합목에 속하는 분류군들과 가까운 유연관계를 보이지 않았다. 이전의 은방울꽃과 [Ruscaceae] 내에 취급되었던 애기나리속, 나도옥잠화속, 죽대아재비속 등은 각각 Colchiaceae, 백합과, Calochortaceae로 이전 되어야 한다는 결론이 내려졌다. 마지막으로 한국산 백합강에 속하는과의 체계에 대해서 토의하였다.

주요어 : 한국산 백합강, 분자생물학적 자료, 비짜루목, 백합목

*교신저자 : 전화 : 43-1-4277 54141, 전송 : 43-1-4277 9541

e-mail : polygonatum@hanmail.net