A NUMERICAL TAXONOMIC STUDY OF THE GENUS *LILIUM* IN JAPAN

Yoshito ASANO

(Laboratory of Floriculture and Landscape Architecture, Faculty of Agriculture, Hokkaido University, Sapporo 060, Japan)

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Introduction

Out of over 90 species of the genus *Lilium* in the world, 13–15 species occur in Japan including the most important ornamental ones[18]. Regarding the classification of the genus, the latest one was established by COMBER[4] after several basic studies by others. He divided the genus *Lilium* into seven sections based on 15 taxonomic characters. This was partially revised by LIGHTY[6] and DE JONG[5], and a hypothetical evolutional scheme was proposed by the former author[8].

However, when viewed from the interspecific crossability and the fertility of F_1 hybrids, they seem to be still incomplete and need some revision[2,18]. To quantitatively represent the interspecific relationships, the author attempted a numerical approach using multivariate analysis methods based on numerous characters. In this paper, the result of applying to the Japanese species as materials is given. Some consideration about their phylogenetic relationship is also given.

Materials and Methods

The species used in this study are as follows; *L. alexandrae* (WALL.) COUTTS, *L. auratum* LINDL., *L. callosum* SIEB. et ZUCC., *L. concolor* SALISB., *L. dauricum* KER-GAUL., *L. japonicum* THUNB., *L. leichtlinii* HOOK. f. var. *maximowiczii* (REGAL) BAKER, *L. longiflorum* THUNB., *L. medeoloides* A. GRAY, *L. nobilissimum* (MAKINO) MAKINO, *L. rubellum* BAKER, *L. speciosum* THUNB. and *L. tigrinum* KER-GAUL. var. *flaviflorum* (MAKINO) STEARN. These 13 species are all diploid with chromosome numbers 2n=24. A triploid species *L. tigrinum* KER-GAUL. was excluded from this study because this clonal species is of hybrid origin[10,17]. This species was introduced from China to Japan as a food plant in ancient times and spread vegetatively all

TABLE 1. List of characters used for statistical analysis

No.	Character	State code 1—3 or 1—2—3		
1	Flower bud differentiation	In the bulb	—	During stem elongation
2	Flower bud	Glabrous	—	Floccose
3	Inflorescence	Unbellata	—	Racemose
4	Flowers per stem	Few	—	Many
5	Pose of Flower	Pendulous	— Horizontal	— Upright
6	Flower shape	Recurved	— Funnel	— Trumpet
7	Perianth seg. attachment to receptacle	Smooth	—	Rectangular
8	Flower pigment	Carotenoid	— Flavonol	— Anthocyanine
9	Perianth segment size	Small	— Medium	— Large
10	Perianth segment shape	Narrow	— Medium	— Broad
11	Perianth segment, the broadest part	Basal	— Middle	— Upper
12	Perianth segment margin	Straight	—	Undulated
13	Spots on perianth segments	Absent	—	Present
14	Papillae on perianth segments	Smooth	—	Papillose
15	Nectary	Glabrous	—	Margined with pubescent
16	Perianth segment tip, hairiness	Hairless	—	Haired
17	Claws at perianth segment tips	Absent	—	Developed
18	Ovary color	Yellow green	—	Green
19	Relative stigma size (=Stigma width/Style width)	Small	— Medium	— Large
20	Pistil length/Filament length	Lower than 1.2	—	Higher than 1.2
21	Style length/Ovary length	Lower than 1.0	—	Higher than 1.0
22	Filament	Glabrous	—	Pubescent
23	Pollen color	Yellow	— Orange	— Reddish brown
24	Flower scent	Nasty	— Scentless	— Sweet
25	Plant hight	Dwarf	—	Tall
26	Leaf arrangement	Whorled	—	Scattered
27	Leaves per unit stem length	Few	— Medium	— Many
28	Leaf, the broadest part	Basal	—	Middle
29	No. of veins	One	— Three	— Five
30	Petiole	Obscure or absent	—	Obvious
31	Stem, shade	Green	—	Purplish brown
32	Stem, ridge	Smooth	—	Ridged
33	Stems per bulb	One	—	Sometimes two
34	Bulbils in axils	Absent	—	Present
35	Bulblets	Very few	—	Several
36	Habit of underground stem	Erect	—	Stoloniform
37	Basal leaves	Absent	—	Sometimes present
38	Bulb color	White or yellow	—	Purple
39	Imbrication of scales	Loose	—	Close

No.	Character	State code 1—3 or 1—2—3
40	No. of scales	Few — Many
41	Scale, joint	Jointed — entire
42	Scale shape	Narrow — Broad
43	Scale, bitterness	Mild — Bitter
44	Capsule, edge	Roundish — Angular
45	Capsule shape	Spherical — Intermediate — Cylindrical
46	Capsule, ripeness	Rapid — Delayed
47	No. of seeds	Few — Many
48	Seed weight	Light — Medium — Heavy
49	Seed shape	Triangle — Oblong
50	Seed color	Light — Dark
51	Germination type	Hypogeal — Epigeal
52	Germination quickness	Immediate — Delayed
53	Primary leaf shape	Norrow — Broad

over Japan[15]. The materials examined were collected from their natural habitats or commercially obtained. 12 species were each represented by two or more strains, while only one strain was available for *L. tigrinum* var. *flaviflorum*. Data were mostly obtained from these materials and were supplemented by those in descriptions by other workers[15,18,20]. The 53 characters taken for the statistical analysis are listed in Table 1 including all but one of those chosen by COMBER[4] in his study. For each species character states were recorded using code numbers ranging from 1 to 3. Although the majority of the characters were regarded to be stable, individuals belonging to one species did not always show the same development of a character. In such cases, the code number occuring with higher frequency was taken as representative of the species, unless otherwise noticed. No particular weighting was made for the characters. A matrix of 13 species ×53 characters was analysed by cluster analysis and pattern analysis. In cluster analysis, samples (species) are linked hierarchically based on a certain similarity between them, resulting in a dendrogram. As measure of similarity, Euclidean distance was used here, and clustered by unweighted pairgroup centroid method. Pattern analysis, developed by Hayashi, is a quantitative representation method of the similarity between 'response pattern' of samples (species) to variables (characters). The resulting relationship among samples is shown in scatter diagrams[16,22]. The program SPSS-CLUSTER and PPSS2-QUANT3 were used for the execution, respectively,

TABLE 2. Initial Euclidean distances between species based on 53 characters

	L. long.	*L. aura.*	*L. spec.*	*L. alex.*	*L. nobi*	*L. rube.*	*L. japo.*	*L. call.*	*L. conc.*	*L. leic.*	*L. tigr.*	*L. daur.*
L. auratum	8.49											
L. speciosum	9.27	5.66										
L. alexandrae	7.48	6.78	8.49									
L. nobilissimum	7.62	6.63	7.35	5.66								
L. rubellum	7.62	7.87	9.06	6.48	6.16							
L. japonicum	8.31	7.00	8.43	6.08	7.14	4.58						
L. callosum	9.06	10.49	10.30	9.70	9.70	9.59	9.43					
L. concolor	9.27	10.39	10.30	9.80	9.59	9.70	9.54	5.83				
L. leichtl. max.	8.72	9.17	8.72	9.90	9.59	10.00	9.75	7.21	6.63			
L. tigr. flav.	7.87	8.60	8.25	9.70	8.94	9.90	10.05	8.25	7.35	5.48		
L. dauricum	8.49	9.80	10.10	9.59	9.90	9.70	9.85	8.94	7.21	6.48	6.63	
L. medeoloides	10.05	10.05	9.85	9.64	9.85	9.64	9.17	8.31	8.31	8.77	9.64	8.43

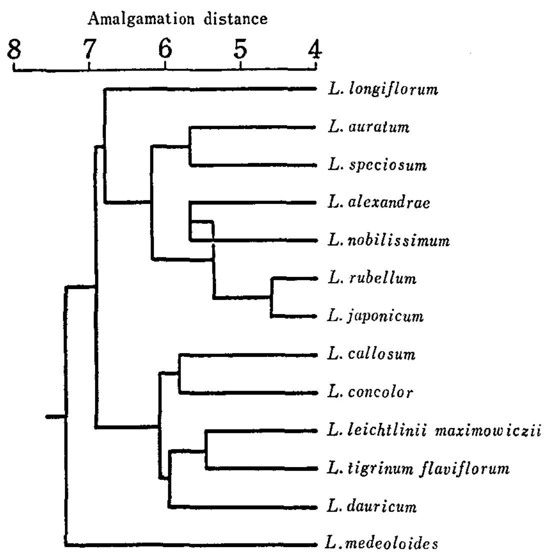

Fig. 1. Dendrogram illustrated by cluster analysis (Euclidean distance, Unweighted pair-group centroid method).

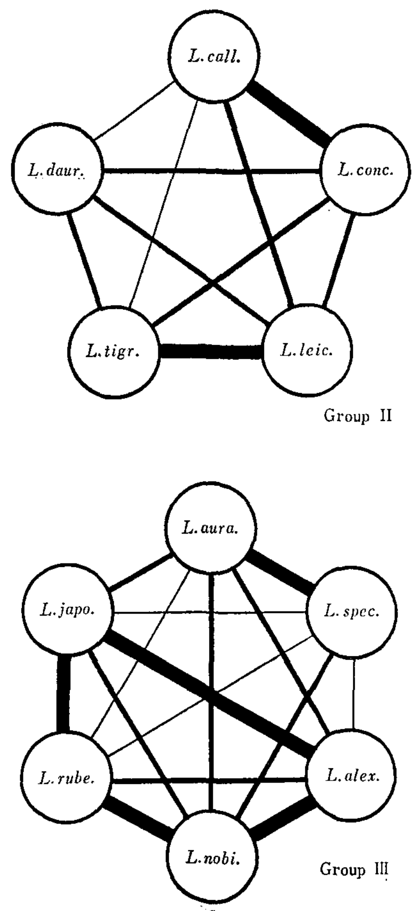

Fig. 2. Diagrammatic representation of intragroup relationships.

Distance betweenspecies; ▬: 6.3>, ▬: 6.3-7.6, —: 7.6<

Results

Cluster analysis: The matrix of the initial Eucledian distances between species is given in Table 2 and a dendrogram constructed is given in Fig. 1. The figure showed that the 13 species investigated were largely divided into four groups when evaluated at the level of an amalgamation distance between

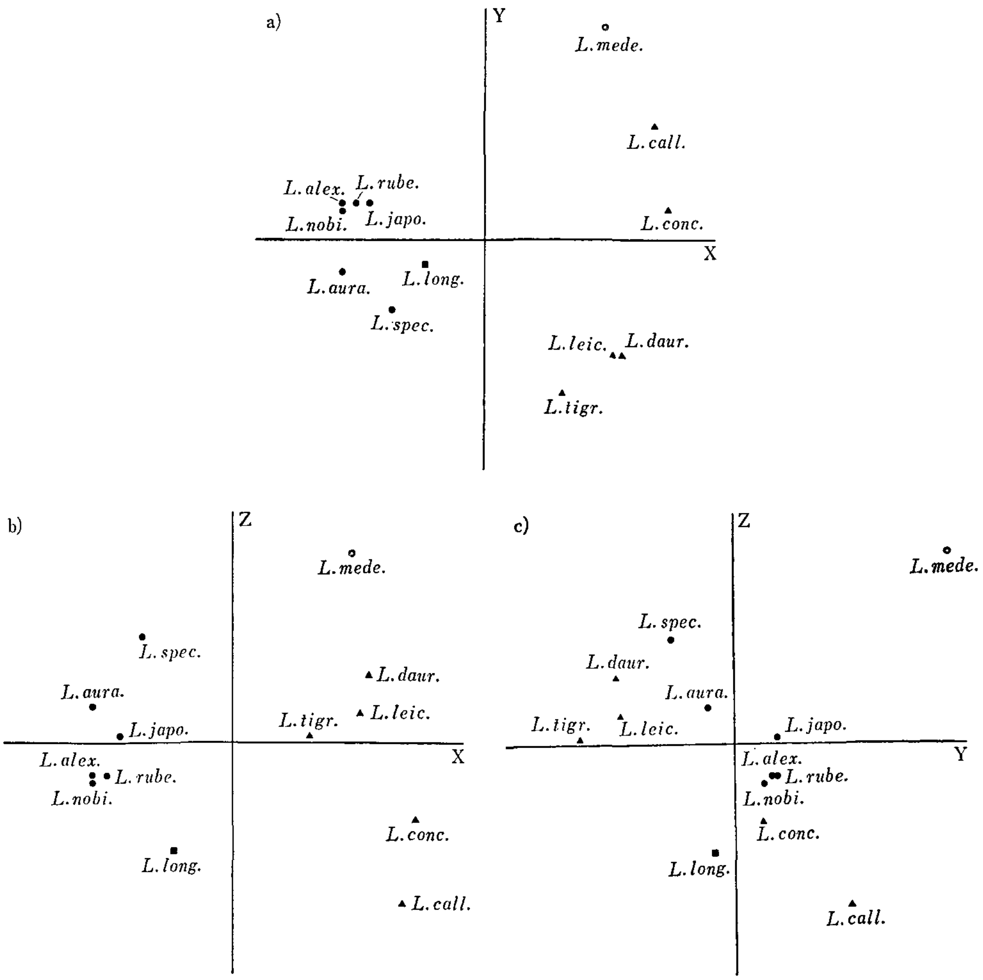

Fig. 3. Scattering diagrams of 13 species illustrated by pattern analysis.
X=The first afctor, Y=The second factor, Z=The third factor
◎: Group I, ▲: Group, II, ●: Group III, ■: Group IV
(according to cluster analysis)
Accumulating eigen value of three factors: 0.6493

6.180 and 6.793 ; Group I (*L. medeoloides*), Group II (*L. callosum, L. concolor, L. leichtlinii maximowiczii, L. tigrinum flaviflorum* and *L. dauricum*), Group III (*L. auratum, L. speciosum, L. alexandrae, L. nobilissimum, L. rubellum* and *L. japonicum*) and Group IV (*L. longiflorum*). Inter-specific relationships within groups, illustrated by the initial distances between species given in Table 2, are shown in Fig. 2.

Pattern analysis : Computation was continued untill the third factor. The scatter diagrams of the 13 species in three two-dimentional spaces are shown in Fig. 3. This result appeared to be largely comparable with the result of the cluster analysis, *i. e.*, four groups of species corresponding to Group I to Group IV were recognized also in Fig. 3. The diagrams showed also that six species corresponding to Group III were closely convergent with each other and that *L. medeoloides* was scattered alone outside of the other species.

Discussion

The resulting grouping of Japanese *Lilium* species in this study agreed with those of LIGHTY[6)] and DE JONG[5)] rather than Comber's original one[4)]. A difference between the both is the position of *L. dauricum* which constitutes a single group in the latter, while is included in *L. tigrinum* group in the former. A high crossability of *L. dauricum* with the members of *L. tigrinum* group indicates their close relationship[15 and others)]. The present result agreed with this fact and supported LIGHTY and DE JONG's view. According to the result, *Lilium* species native to Japan appeared to be divided into four relatively distinct groups ; Group I (one species), II, III and IV (one species). From Fig. 1 and Fig. 3, it may be estimated that both Group II and III are further divided into two subgroups ; *L. callosum* — *L. concolor* and *L. leichtlinii maximowiczii* — *L. tigrinum flaviflorum* — *L. dauricum* for Group II, and *L. auratum* — *L. speciosum* and *L. alexandrae* — *L. nobilissimum* — *L. rubellum* — *L. japonicum* for Group III.

Inter-group phylogenetic relationship : Out of 13 species investigated, *L. medeoloides*, which stood apart from the others in Fig. 1 and Fig. 3, is regarded as the oldest one as measured by having such putatively primitive characters as hypogeal and delayed germination, whorled leaves, jointed scales and heavy seeds at the same time and by the absence of specialized morphological features[4,6,8)]. From the evidence of crossabilty, Group II probably comes next. Inter-group crosses made so far showed that successful cases were only between Group I (*L. medeoloides*) and certain members of

Group II: *L. concolor*, *L. leichtlinii maximowiczii* and *L. dauricum*, indicating a closer relationship of *L. medeoloides* to Group II rather than to Group III or IV (ASANO, unpublished).

The geographical distributions of the 13 species concerned is shown, as another aspect to be considered, in Fig. 4. This figure clearly showed the difference in distribution patterns between groups. That is, the species belonging to Group I and II were found commonly distributed over the eastern Asian Continent and Japan, in contrast to those belonging to Group III and IV which were narrowly limited to an area in and around the Japanese Islands. It is suggested that such species as the former had distributed in what is called 'Makinoesia Region' in Oligocene epoch, from where the Japanese Islands were isolated later[1,9]. It is likely the latter have adaptively differenciated in and around the Japanese Islands after their isolation. The supporting evidences for the recent origin of the members of Group III may be 1) the higher intragroup resemblance than Group II (Fig. 3) and 2) the occurrence of natural interspecific hybrids within the group such as *L. auratum* × *L. speciosum* and *L. japonicum* × *L. auratum*[13,15]. An attempt,

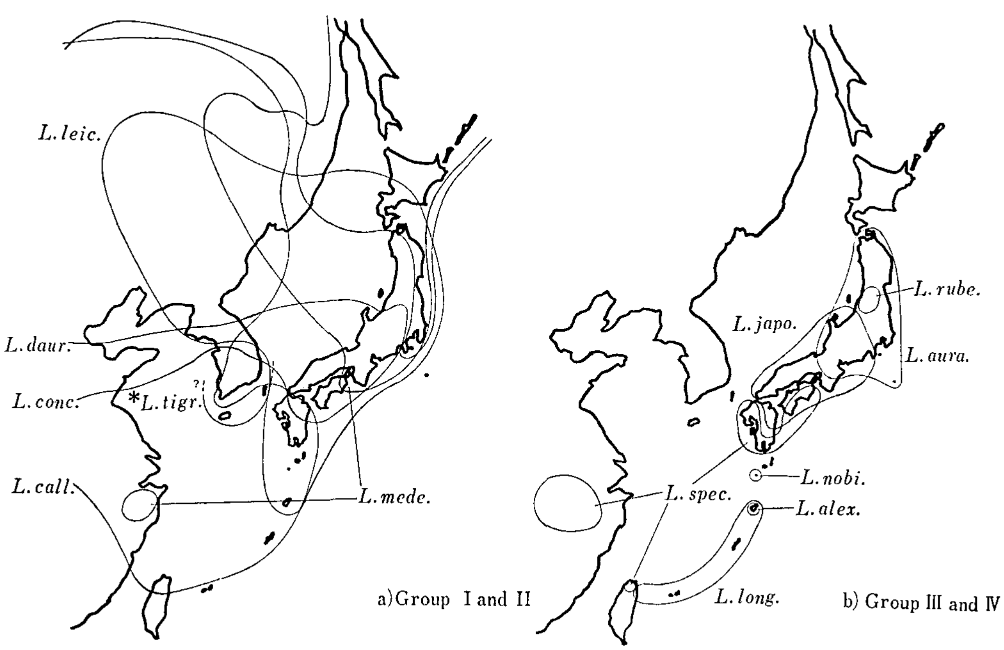

Fig. 4. Geographica ldistribution of the 13 species of *Lilium* studied[3,7,11,12,14,15,18,19,21].

* Diploid form of *L. tigrinum*, including the yellow variety *flaviflorum*

using the data in Table 2, to array the 13 species concerned according to their distances from the putatively oldest species, *L. medeoloides*, resulted largely in the order of Group I, II, III, IV. Thus, it may be concluded that Japanese *Lilium* species have originated in the order of Group I, II, III or IV with increasing phenetic differenciation.

Summary

A numerical taxonomy of 13 species of *Lilium* in Japan was attempted using multivariate analysis methods for 53 characters. Both cluster and pattern analysis showed that they were divided into four groups; Group I (one species), II, III and IV (one species). A consideration about inter-group phylogenetic relationship is given.

Literature Cited

1. ABE, S. and T. TAMURA: Studies on the natural variation of *Lilium speciosum*. Studies on the bulbs for exporting (Tulips and *Lilium speciosum*). (ed. M. SHISA) Seibundo Shinko-sha Co. Ltd. Tokyo. (in Japanese) 1955.
2. ASANO, Y.: Chromosome association and pollen fertility in some interspecific hybrids of *Lilium*. *Euphytica* **31**: 121–128. 1982.
3. BARANOVA, M. V.: The geographical distribution of *Lilium* species in the flora of the USSR. *Lily Yearbook, R.H.S.* **32**: 39–55. 1969.
4. COMBER, H. F.: A new classification of the genus *Lilium*. *Lily Yearbook, R.H.S.* **13**: 85–105. 1949.
5. DE JONG, P. C.: Some notes on the evolution of Lilies. *Lily Yearbook, N.A.L.S.* **27**: 23–28. 1974.
6. LIGHTY, R. W.: Cytological and interspecific hybridization studies in *Lilium* L. and their significance for classification. Ph. D. thesis, Cornell Univ. 1960.
7. LIGHTY, R. W.: The lilies of Korea. *Lily Yearbook, R.H.S.* **31**: 31–39. 1968 a.
8. LIGHTY, R. W.: Evolutionary trends in lilies. *Lily Yearbook, R.H.S.* **31**: 40–44. 1968 b.
9. MAEKAWA, F.: Makinoesia and its bearing to Oriental Asiatic flora. *J. Jap. Bot.* **24**: 91–96. (in Japanese) 1949.
10. NODA, S.: Cytogenetics on the origin of triploid *L. tigrinum*. *Bull. Osaka Gakuin Univ.* **6**: 85–140. (in Japanese) 1966.
11. NODA, S.: Chromosomes of diploid and triploid forms found in the natural populations of tiger lily in Tsushima. *Bot. Mag. Tokyo* **91**: 279–283. 1978.
12. NODA, S. and K. RIH: The relationship between chromosome structures and three Liliaceae plants and human activities. An interim report of overseas scientific investigation by the Education Ministry "The history of environmental changes in Korea": 33–55. (in Japanese) 1980.
13. OGIHARA, R.: Intra-specific variation of karyotype in natural population of

Lilium japonicum from the Izu peninsula. *La Kromosomo* **66**: 2135–2144. (in Japanese) 1966.
14. PEKING BOTANICAL INSTITUTE: Iconographia Cormophytorum Sinicorum Tomus V. Kagakushuppan-sha Co. (in Chinese) 1976.
15. SHIMIZU, M.: Lilies of Japan. Seibundo Shinkosha-sha Co. Ltd. Tokyo. (in Japanese) 1971.
16. SNEATH, P. H. A. and R. R. SOKAL: Numerical taxonomy. W. H. Freeman and Co. San Francisco. 1973.
17. SON, J.: Karyotype analysis of *Lilium lancifolium* Thunberg by means of C-banding method. *Japan. J. Genetics* **52**: 217–221. 1977.
18. SYNGE, P. M.: Lilies. B. T. Batsford Ltd. London. 1980.
19. WILSON, E. H.: The lilies of eastern asia. Dulau & Co. Ltd. London. 1925.
20. WITHERS, R. M.: Liliums in Australia. The Australian Lilium Soc. 1967.
21. WONG, F.: Distribution of Chinese lilies and their culture. *Chinese Bot. Mag.* **1**: 41–52. (in Chinese) 1934.
22. YASUDA, S.: Social statistics. Maruzen Co. Ltd. Tokyo. (in Japanese) 1969.