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Quantitative Taxonomic Studies on the Group of *Salix pseudo-lasiogyne* Growing in Korea[1]

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韓國産 능수버드나무類의 数量的 分類에 關한 硏究[1]

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ABSTRACT

Classification on the group of *Salix pseudo-lasiogyne* growing in Korea, was conducted using cluster analysis, factor analysis, and principal component analysis. Thirty-six characters (Table 2) of the 5 basic species were measured. The phenograms and ordination plot showing the relationships between the species were made by applying the cluster analysis and principal component analysis. Five important factors, such as leaf blade width, number of right serration, angle of leaf apex, number of flowers in an ament, and the ratio of petiole length to width, were inferred from the rotated factor matrix, and their state values were presented in polygonal diagram. *Salix pseudo-lasiogyne* and *S. babylonica* were similarly correlated and linked in one group, *S. dependens* and *S. matsudana* for. *tortuosa* were secondarily linked in the other group. *S. koreensis* appeared as an alienated species from each of the two groups.

Key Words: Salix; classification; cluster analysis; principal component analysis; factor analysis.

要　　約

韓國産 능수버드나무類에 대한 識別과 形質變異에 관한 分類學的인 問題들을 解決하기 위하여 水原市內에 街路樹로 植栽된 능수버드나무類 5種에 대하여 1982年 4月부터 10月에 걸쳐 꽃과 잎의 36가지 特性을 測定하여 類集分析, 主要因分析 및 要因分析 等의 方法을 利用하여 數量的 分類를 試圖하였다. Mahalanobis′ distance에 의한 分類結果는 능수버들과 수양버들이 가장 먼저 聯關되고, 개수양버들과 용버들은 다음에 聯關되었으며 버드나무는 이들 種으로부터 떨어져서 이들과 聯關되었는데, 이 結果는 Lattice distance와 Euclidean distance에 依한 結果와 同一하였다. 類集分析을 함에 있어서 器官數와 形質數를 늘릴 수록 種들 相互間에 類集이 더욱 效率的으로 나타났고, 主要因分析에 依한 種間 關係는 類集分析에 의한 結果와 같았으며, 第1, 第2, 第3의 主要因子가 種間關係를 說明할 수 있는 分散은 62.2%이었는데, 要因分析의 結果 葉身幅, 鋸齒數, 葉角, 한 花穗에 달린 꽃의 數 및 葉柄長比 等이 이들 種을 分類 識別함에 있어서 主要한 形質 要因임이 確認되었다. 이러한 數量的 分類는 種間 關係를 說明하고 主要形質要因을 推論하는데 效果的이었다.

INTRODUCTION

The genus *Salix* of Salicaceae consists of more than 300 species[5,10,12,17], and is chiefly distributed in northern temperate climate. Certain species

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are important as ornamentals[8,20].

Salix koreensis collected at East Coast by Admiral Schlippenbach of Germany was the first species of Korean willow introduced to the botanical world, which was named by Andersson[28]. To give a brief history on Korean willows, Komarow[16] reported 9 species, and Nakai[27] reported 15 species including *S. babylonica*. Léveillé[24] added 9 new species including *S. pseudo-lasiogyne*. Mori[26] enumerated 38 species, including *S. neo-lasiogyne* and *S. neo-lasiogyne* var. *glabrescens*. Rehder[32] introduced 3 species of Korean willows. Nakai[28] named *S. dependens* as a new species of the genus *Salix* and summed up all the studies on Korean willows with illustrations, and classified 6 species under the section *Subfragiles*, among which *Salix babylonica*, *S. elegantissima*, and *S. matsudana* for. *tortuosa* were included. He[29] identified 25 species, 14 varieties, and 1 forma of Korean willows. Chung *et al.*[2] enumerated 31 species with Korean common names. Chung[3,4,13] published 28 species, 14 varieties, and 2 forms of Korean willows with line drawings and their distribution. Lee[18,19,20,21] enumerated 48 taxa, and published 31 species, 12 varieties, and 3 forms of Korean willows with line drawings.

This study was stimulated by the fact that many characters have not been clearly distinguished between species in the weeping habits and character variations of flowers and leaves. So *Salix babylonica*, *S. pseudo-lasiogyne*, and *S. dependens* were often confused for their identification. Therefore the problems to be solved were to find out whether the species were really distinct and what was the most important factor classifying these species. In solving these problems, a method that presents the variation patterns more objectively and quantitatively is needed, while some criteria for objective decisions as to the level of taxa to be recognized should be simultaneously provided. Crovello[6] concluded that numerical taxonomy was successful in providing a better description of variations within a section and within the genus *Salix*, both in resolution and in ease of comprehension.

The main objective of this study is to attempt a solution to the taxonomic problems and character variations within the closely related group of *Salix pseudo-lasiogyne* using the techniques of numerical taxonomy.

MATERIALS AND METHODS

1. Plant materials

Among the genus *Salix* growing in Korea, the following species, the group of *Salix pseudo-lasiogyne*, were studied; *Salix koreensis*, *S. pseudo-lasiogyne*, *S. babylonica*, *S. dependens*, and *S. matsudana* for. *tortuosa*[2,3,4,7,11,13,18,19,21,23,24,25,28,30,31,32,34,35].

2. Sample collection

All the individual trees are the Operational Taxonomic Units (OTUs) to be classified[33]. The materials used for this study were collected from the 20-year-old street trees (4 treatments per species) in Suweon. The 20 OTUs were studied as basic species from the 140 OTUs including seemingly-hybrids. Samples were collected from the vigorous branch toward the south. To measure all the possible characters, flowers, young leaves, and mature leaves were collected in April, May, and September, 1982 respectively.

3. Measurement

All the characters were measured 4 times, and the average values were used in obtaining the basic data matrix for an OTU. Measured quantitative morphological characters and their states are shown in Table 1.

4. Computational analysis

The state values were given to each of the character variables after all the measurements were done. To give equal weight between the species, 20-rowed data matrix (5 species, 2 replications, 2 sexes) was made from the raw data (Table 2). Correlation coefficients between the characters were computed from the data matrix.

Table 1. Characters and their states.

Organs	Characters	States	
Leaf	Blade, length and width	Measured in tenths of millimeters	
	Number of serration, left and right	The number observed	
	Petiole, length and width	Measured in tenths of millimeters	
	Angle of leaf, apex and base	The number observed	
	Trichome, abaxial and adaxial surface	1. Rare-absent	2. Medium-dense
Ament	Length and width	Measured in tenths of millimeters	
	Number of flowers	The number observed	
	Number of flower leaves	The number observed	
	Peduncle length	Measured in tenths of millimeters	
Flower	Trichome of abaxial bract	1. On the whole surface	2. Bellow the middle
		3. At margin	4. At base
	Trichome of adaxial bract	1. Rare-absent	2. Medium-dense
	Shape of bract	1. Organ widest at proximal end	
		2. Organ widest at midpoint	
	Apex of bract	1. Organ with rounded tip	2. Organ with pointed tip
	Trichome of ovary	1. On the whole surface	2. Bellow the middle
		3. Rare	4. Absent
	Style distinction	1. Unobserved	2. Rare-medium
		3. Distinctive	
	Color of anther	1. Yellow	2. Red-black
	Trichome of filament	1. Absent	2. Rare
		3. Medium-dense at the proximal end	
	Filament cohesion	1. Unobserved	2. Rare
		3. Coherent at the proximal end	

After group means and variance-covariance matrices (i.e., total, among, within, and pooled variance-covariance matrices) were computed, Mahalanobis' distances were used in clustering[33]. The D^2 between any pair of points f and g in the D-space can be obtained by the equation;

$$D_{fg}^{2} = S_{fg}' W^{-1} S_{fg}$$

where, W^{-1} denotes inverse matrix of within-group (pooled) variance-covariance matrix, and S_{fg} denotes vector of differences of means. Then the square root of D^2 is the Mahalanobis' distance in the D-space[22].

Selected characters were used at each steps of clustering. To reduce the variation of characters seemingly influenced by the environmental conditions, the ratios of leaf length to width, petiole length to width, and the angle (degree) ratio of leaf apex to base were also used instead of each one character. Lattice and Euclidean distances were also used to revalidate the results above. Three linkages (i.e., single, complete, and average linkages) were shown in each phenogram.

Principal component analysis and factor analysis[9,14,15] were performed to know the phenetic relationships and to get the important factors affecting the phenetic variations between the species. Ordination plot was made from the first two principal components. Important factors were inferred from the rotated factor matrix. Polygonal diagram was made from the mean values of the 5 characters to compare the character states among the species.

All the statistical computations were done using the computer system HP 3000, in College of Agriculture, Seoul National University.

Voucher specimens are preserved in the Herbarium Facultatis Agriculturae Suwonensis (HAS),

Table 2. The state values of characters measured.

Organs		Mature leaves										
Species	Sex	Leaf blade (mm) Length	Leaf blade (mm) Width	Number of serration Left	Number of serration Right	Petiole (mm) Length	Petiole (mm) Width	Angle of leaf (degree) Apex	Angle of leaf (degree) Base	Trichome of petiole Lateral	Trichome of petiole Adaxial	Trichome of petiole Abaxial
Salix koreensis	Female	87.0	17.5	48.3	46.0	8.3	1.1	32.5	65.0	1	2	1
		93.5	18.5	47.8	49.3	8.0	1.1	26.3	70.0	2	2	1
	Male	96.5	18.9	49.0	51.0	9.4	0.8	26.3	70.0	2	2	1
		115.5	18.5	52.8	52.8	8.2	1.1	18.8	66.3	2	2	1
Salix pseudo-lasiogyne	Female	109.8	12.0	40.8	39.3	9.4	1.0	11.3	35.0	2	2	1
		96.5	13.5	30.0	30.3	9.5	1.4	16.3	43.8	2	2	1
	Male	88.8	15.0	43.5	43.3	8.4	1.1	26.3	41.3	1	2	1
		126.0	16.8	59.3	62.0	12.5	1.0	17.5	55.0	1	1	1
Salix babylonica	Female	98.3	14.0	31.5	30.8	9.2	1.3	21.3	43.8	1	2	1
		137.8	17.5	43.3	43.3	9.8	1.0	11.3	47.5	2	2	1
	Male	122.5	20.2	52.8	53.5	10.8	0.9	26.3	70.0	1	1	1
		131.5	14.8	41.3	41.8	13.5	1.2	13.8	38.8	2	2	1
Salix dependens	Female	85.5	10.5	33.3	35.3	6.9	1.1	16.3	42.5	1	2	1
		105.3	11.0	35.0	34.3	8.1	1.1	13.8	42.5	1	2	1
	Male	87.0	12.5	37.0	38.8	6.8	1.0	13.8	43.8	1	2	1
		64.5	12.5	36.3	37.0	7.4	0.9	25.0	52.5	1	2	1
Salix matsudana for. *tortuosa*	Female	99.3	13.6	47.3	47.5	8.6	1.2	15.5	52.5	1	2	1
		84.2	13.5	49.5	49.0	8.1	1.0	22.5	51.3	1	2	2
	Male	63.0	11.4	41.3	42.8	6.2	0.8	26.3	40.0	1	1	1
		81.0	10.0	42.0	39.8	5.5	2.7	15.0	45.0	1	2	1

Organs		Ament					Flower			(Female)		(Male)		
Species	Sex	Length (mm)	Width (mm)	Number of flowers	No. of flower leaves	Peduncle length (mm)	Trichome of bract Abaxial	Trichome of bract Adaxial	Trichome of bract Apex	Trichome of ovary	Style distinction	Anther color	Trichome of filament	Cohesion of filament
Salix koreensis	Female	19.1	4.1	54	4	4.3	2	2	2	1	3			
		17.5	5.2	53	3	4.0	3	2	2	1	3			
	Male	25.4	6.2	44	2	5.9	2	1	3			2	3	2
		28.1	7.1	56	2	3.7	2	1	3			2	3	2
Salix pseudo-lasiogyne	Female	24.6	5.9	37	5	8.4	4	2	2	3	2			
		22.0	6.6	62	4	7.9	4	2	2	2	1			
	Male	28.0	5.7	87	3	5.2	2	2	2			1	2	2
		35.0	4.3	78	3	9.4	2	2	2			1	2	1
Salix babylonica	Female	14.1	3.3	41	2	5.0	4	2	1	3	2			
		21.5	6.4	45	4	11.1	4	2	2	4	2			
	Male	25.1	5.4	45	3	4.4	4	1	2			2	3	3
		17.6	5.7	49	4	2.9	4	2	2			2	3	3
Salix dependens	Female	11.0	3.6	34	4	3.3	3	2	2	4	1			
		19.7	4.5	58	4	6.0	4	2	2	4	2			
	Male	17.0	5.7	59	2	3.3	2	2	2			1	2	2
		24.5	5.5	38	4	5.5	2	2	2			1	2	1
Salix matsudana for. *tortuosa*	Female	14.2	6.5	46	3	4.1	4	2	2	3	2			
		14.1	7.0	49	4	4.4	4	2	2	3	2			
	Male	11.2	3.8	44	2	3.1	4	2	2			2	2	1
		19.8	4.9	50	2	4.9	4	2	2			2	2	1

Four characters of trichome of mature leaves and 8 characters of young leaves were measured, but they were omitted in this Table 2.

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RESULTS AND DISCUSSION

Certain characters showed high correlation with other characters. Table 3 shows the correlation coefficients between the characters. Among them, leaf blade width is most highly correlated to the number of serration, angle of leaf base, and the presence of the trichome of adaxial bract. Thus this result is considered good for interpretation.

Table 3. Correlation half matrix between the characters.

# Characters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Leaf blade length	1.00	.50	.34	.35	.80	-.11	-.45	.12	.48	-.11	.19	-.27	.10	.43	.27	.14	.21	.47
2. Leaf blade width		1.00	.66	.69	.50	-.38	.44	.81	.41	-.20	-.34	-.66	.41	.48	.29	.18	-.17	.14
3. Number of left serration			1.00	.98	.33	-.19	.32	.67	.04	-.45	-.32	-.47	.47	.50	.25	.29	-.20	.04
4. Number of right serration				1.00	.36	-.29	.31	.67	.06	-.50	-.36	-.48	.49	.49	.24	.29	-.22	.05
5. Petiole length					1.00	-.29	-.15	0.9	.37	-.24	.08	-.16	-.02	.44	.16	.20	.29	.36
6. Petiole width						1.00	-.29	-.20	-.10	.26	.28	.22	-.18	-.09	-.08	.05	-.20	-.04
7. Angle of leaf apex							1.00	.59	-.25	-.25	-.41	-.28	.09	.03	-.22	.09	-.24	-.36
8. Angle of leaf base								1.00	.13	-.17	-.41	-.65	.46	.30	.18	.02	-.27	-.13
9. Trichome of petiole, lateral side									1.00	.31	0.7	-.28	.45	.23	.52	-.12	.18	.31
10. Trichome of petiole, adaxial side										1.00	-.06	.22	.05	-.23	.33	-.14	.24	-.06
11. Trichome of bract, abaxial side											1.00	.24	-.45	-.49	.00	-.41	.24	.09
12. Trichome of bract, adaxial side												1.00	-.67	-.40	-.33	.10	.39	.13
13. Trichome of bract, apex													1.00	.41	.55	.08	-.17	-.04
14. Ament length														1.00	.28	.54	.01	.54
15. Ament width															1.00	.10	.13	.17
16. Number of flowers in an ament																1.00	-.16	.17
17. Number of flower leaves in an ament																	1.00	.37
18. Peduncle length of an ament																		1.00

Underlined coefficients manifest the characters between which show correlation higher than 0.60.

Figures 1 to 5 show the phenograms made from the results of cluster analysis using the Mahalanobis' distance. The relationships were shown on the basis of 19 leaf characters including the trichomes of surfaces (Fig. 1), 13 leaf characters including the trichomes of petiole (Fig. 2), 18 characters of leaf, female-flower, and ament (Fig. 3), 19 characters of leaf, male-flower, and ament (Fig. 4), 21 characters of leaf, the trichomes of petiole and bract, and ament (Fig. 5). When the species were clustered on the basis of leaf only (Fig. 1), or on leaf, female-flower, and ament (Fig. 3), the results showing the relationships were not so good for interpretation. It was observed that the more the organs and characters used, the better the species clustered (Figures 2,4, and 5). Cluster analysis using the Lattice distance and the Euclidean distance provided similar results obtained by cluster analysis using the Mahalanobis' distance (Figures 6 and 7). The phenograms were almost the same at each linkage.

ABBREVIATION

Linkages

- I: Single linkage
- II: Complete linkage
- III: Average linkage

Species

- K: *Salix koreensis*
- P: *Salix pseudo-lasiogyne*
- B: *Salix babylonica*
- D: *Salix dependens*
- M: *Salix matsudana* for. *tortuosa*

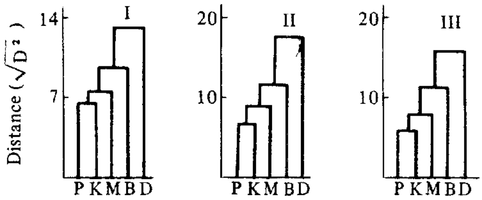

Fig. 1. Phenograms based on 19 leaf characters including the trichomes of surfaces and the ratios mentioned.

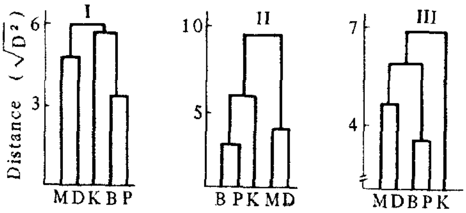

Fig. 2. Phenograms based on 13 leaf characters including the trichomes of petiole and the ratios mentioned.

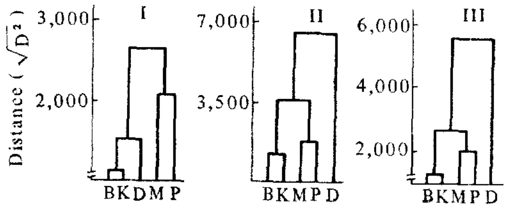

Fig. 3. Phenograms based on 18 characters of leaf, female-flower, and ament.

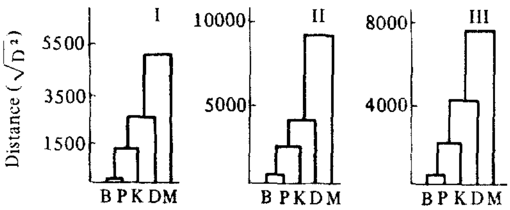

Fig. 4. Phenograms based on 19 characters of leaf, male-flower, and ament.

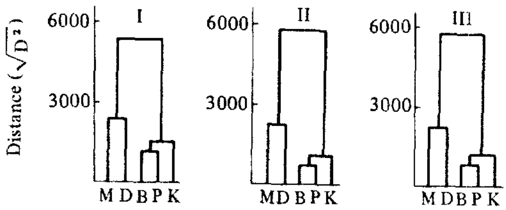

Fig. 5. Phenograms based on 21 characters of leaf, the trichomes of petiole and bract, and ament.

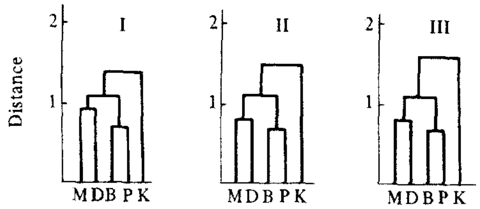

Fig. 6. Phenograms based on 20 characters using the Lattice distance.

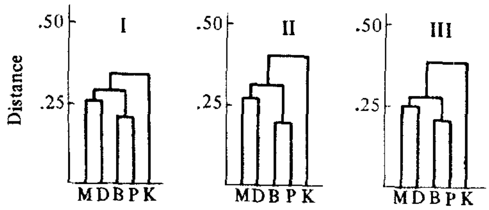

Fig. 7. Phenograms based on 20 characters using the Euclidean distance.

Figure 8 shows the ordination plot made from the result of principal component analysis. Ordination plotting of the first against second principal component enabled to detect undue distortion, imposed upon the natural multidimensional configuration of species, by the representation within a space of reduced dimensionality[1]. The percentage of variances encompassed by the first three components were 30.5, 20.6, and 11.1 respectively. The greater portion of total variances has been encompassed by the first two components. The results were similar to those from the cluster analysis. From this, it was concluded that ordination by the principal component analysis could afford

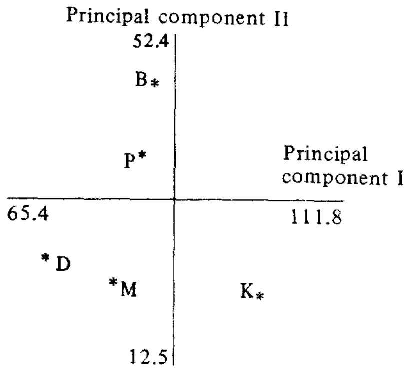

Fig. 8. Ordination plot from the results of principal component analysis.

the reduced dimensionality representing an adequate proportion of the total variance objectively.

Accordingly, *Salix pseudo-lasiogyne* and *S. babylonica*, were similarly correlated and linked in one group, *S. dependens* and *S. matsudana* for. *tortuosa* were secondarily linked in the other group, but *S. koreensis* was alienated from each of the two groups of species.

Figure 9 shows that leaf width, number of right serration, angle of leaf apex, number of flowers in an ament, and ratio of petiole length to width were important factors. All of these factors should be considered in a group.

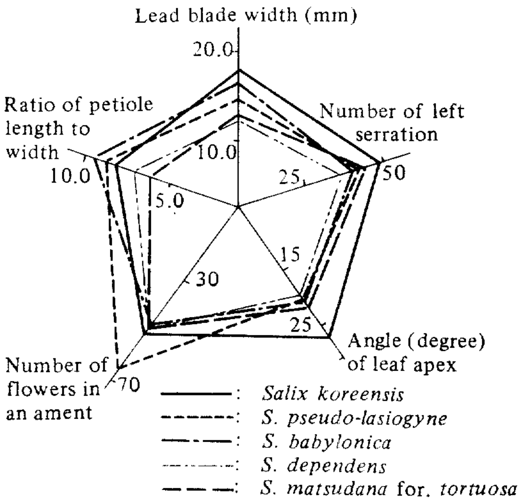

Fig. 9. Polygonal diagram based on the mean values of the 5 characters inferred from the factor analysis.

The main points in applying the cluster analysis, principal component analysis, and factor analysis to classify the genus *Salix* were whether these methods could present the variation pattern objectively and quantitatively, and simultaneously provide some criteria for objective decisions as to the level of taxa to be recognized. Phenograms, ordination plot, and polygonal diagram represented satisfactorily for all of these.

CONCLUSION

Numerical taxonomy using the cluster analysis, principal component analysis and factor analysis was successful in providing a better description on the patterns of relationships, as well as in inferring the important factors affecting the character variations on the group of *Salix pseudo-lasiogyne* growing in Korea.

The results showed that the more the organs and characters used, the better the species clustered. The results from the Mahalanobis' distance in cluster analysis were revalidated by using the Lattice distance and the Euclidean distance.

The results presented by the principal component analysis were almost the same as those from the cluster analysis. It was concluded that ordination using the principal component analysis could afford the reduced dimensionality representing 62.2% of the total variance by the first three components.

Salix pseudo-lasiogyne and *S. babylonica* were firstly grouped, *S. dependens* and *S. matsudana* for. *tortuosa* were secondarily linked, but *S. koreensis* was alienated from each of the two groups of species.

Five factors inferred from the rotated factor matrix were considered important to classify the genus *Salix* growing in Korea; leaf blade width, number of right serration, angle of leaf apex, number of flowers in an ament, and the ratio of petiole length to width.

LITERATURE CITED

1. Challice, J.S., and M.N. Westwood. 1973. Numerical taxonomic studies of the genus *Pyrus* using both chemical and botanical characters. Bot. J. Linn. Soc. 67:121-148.
2. Chung, T.H., *et al.* 1937. Common names of Korean plants. Society of Korean Naturalist: 40-43.
3. Chung, T.H. 1957. Korean flora(Woody plants). Shinji Pub. Co.: 359-381.
4. Chung, T.H. 1965. Illustrated fauna and flora of Korea(Flora). Ministry of Education: 779-802.

5. Cronquist, A. 1968. The evolution and classification of flowering plants. Houghton Mifflin Co. 396pp.
6. Crovello, T.J. 1966. Quantitative taxonomic studies in the genus, *Salix*. Ph.D. Thesis, Univ. of Calif., Berkeley. 341pp.
7. Engler, A. 1964. Syllabus der Pflanzenfamilien I. Gebürder Borntraeger, Berlin: 45-46.
8. FAO. 1980. Poplars and willows in wood production and land use. FAO Forestry Series No. 10, Rome: 46.
9. Gnanadesikan, R. 1977. Methods for statistical data analysis of multivariate observations. John Wiley & Sons, New York. 311pp.
10. Grant, V. 1971. Plant speciation. Columbia University Press, New York. 435pp.
11. Hillier. 1978. Hilliers' manual of trees & shrubs. Hillier Nurseries(Winchester) Ltd., England: 349-358.
12. Jones, S.B.Jr., and A.E. Luchsinger. 1979. Plant systematics. MrGraw-Hill Book Co., U.S.A.: 259.
13. Kawamoto, T.K. 1943. Illustrated forest flora of Korea. Society of Korean Naturalist. Seoul. 769pp.
14. Kim, J.T, 1980. A study on factor analytic procedure for privacy in Architecture. Jour. Kor. Assoc. Architecture 24:51-56.
15. Kim, K.W. 1976. Methodolody for social science. Pagyoung Pub. Co. : 456-472.
16. Komarov, V. 1903. Flora Manshuriae II. Acta Horti Petropolitani XXII: 10-38.
17. Lee, T.B. 1964. Plant taxonomy. Hyangmoon Pub. Co., Seoul: 125-126.
18. Lee, T.B. 1973. Illustrated woody plants of Korea. Forest Experiment Station: 13-22.
19. Lee, T.B. 1974. Dendrology. Hyangmoon Pub. Co., Seoul: 105-120.
20. Lee, T.B. 1976. Vascular plants and their uses in Korea. Bull. of the Kwanak Arboretum 1:18-19.
21. Lee T.B. 1980. Illustrated flora of Korea. Hyangmoon Pub. Co., Seoul: 256-264.
22. Lee, Y.M. 1980. Varietal classification on the basis of multivariate analysis and combining ability between each varietal groups in paddy rice. Kor. J. Breeding 12(2):61-92.
23. Lee, Y.N. 1976. Illustrated flora and fauna of Korea (Flowering plants). Ministry of Education. 18:172.
24. Léveillé, H. 1912. Fedde, Repertorium Novarum Specierum. Regni Vegetabillis X:435-437.
25. Makino, T., *et al.* 1921. General view on the flora of Japan. Shinyodo Pub. Co.: 161-167.
26. Mori, E. 1922. Enumeration of Korean plants. Government-general. Seoul: 109-111.
27. Nakai, T. 1911. Flora Koreana II. J. Coll. of Science, Tokyo. 31:211-215.
28. Nakai, T. 1930. Flora sylvatica Koreana. Vol. 18. Society of National Literature Publication. Tokyo: 23-224.
29. Nakai, T. 1952. A synoptical sketch of Korean flora. Bull. of Nat. Sci. Museum, Tokyo. 31:78-79.
30. Ohwi, J. 1961. Flora of Japan. Shibundo, Tokyo: 398-408.
31. Okuyama, S.K.(ed.) 1977. Terasaki's illustrated flora of Japan. Heibonsha Pub. Co., Tokyo: 98-104.
32. Rehder, A. 1927. Manual of cultivated trees and shrubs. The MacMillan Co., U.S.A: 71-111.
33. Sneath, P.H.A., and R.R. Sokal. 1973. Numerical Taxonomy, W.H. Freeman and Co., San Francisco. 573pp.
34. Uehara, K. 1959. Illustration of trees. Youmei Book Co., Tokyo. 1:528-563.
35. Willdenow, C.L. 1805. Species plantarum 4(2): 653-710.