Population's Limit of *Corydalis* (Sect. Pes-gallinaceua) Group Living in the Same Area

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ABSTRACT : To clarify whether the closely related species living in the same area is a population or populations ecologically, leaf morphology, specific leaf area, and fruit and seed production were studied in the natural group of sect. Pes-gallinaceua of *Corydalis* of Namhansansung area from 1999 to 2000. There were 352 plants in one square meter and total eight species or varieties were identified. Of the 352 plants, the number of *C. turtschaninovii* was the most with 103(29.3%), and that of *C. ambigua* was the next with 78(22.2%), and that of *C. turtschaninovii* var. *fumariaefolia* was the smallest with 9(2.6%). In the 28 plants having spotted leaves, central leaflet did not parted or again parted. The extent of partition with the plant was various from non-parted type to perfectly two-parted type (three leaflet). Between two extreme types, there were diverse types so that this character formed a gradient. The rate of length/breadth was in the range of 0.79~2.17. This character was related to the extent of leaflet partition but did not well expressed the distinguishing trait along a species. The number and the type of serration were diverse and there was no sharp borderline among the species or varieties. Ecological properties, specific leaf area, the number of fruit per plant, and the number of seed per fruit, varied with a wide range in a species or variety but differences between species or variety were not significant. Therefore, the *Corydalis* group studied was regarded as a population on the three criteria: (1) possibility of interbreeding, (2) continuity of leaf morphology, (3) irrelevance between character and species, (4) similarity of several ecological properties.

Key words : Closely related species, *Corydalis*, Leaf morphology, Leaflet, Population, Same area, Serration

INTRODUCTION

Plant population ecology is based on unit of a population (Harper 1977). In this time, a population means the group which is genetically same and lives under similar environment, in the same area (Harper 1980). There would appear to be three prerequisites for the successful occurrence of closely related species together in the same area: (1) the species must have acquired differences in breeding behaviour, (2) the species must be able to tolerate the hazards which occur in the area in which they live together, (3) the species must differ from each other in such a way that they do not enter into a struggle for existence in which one succeeds at the expense of the other (Harper *et al.* 1961). By the way, if closely related species live in the same area, there are considerable difficulties about definition or limit of a population (Harper *et al.* 1961). Especially, closely related species in sympatric speciation often live in the same area because those demand for similar environments, and have a similar morphology so that the separation of assemblage into characteristic population is difficult. The other hand, if morphological differences between species are conspicuous, identification for species or setting the limits of a population is carried out easily regardless of common gene pool, but if character states are gradient or slight, it is difficult to set a population in the field. And classifying criteria in plant systematics come from characters based on not only reproductive organs but also vegetative ones, but setting the limits of a population in ecology are mainly depended on vegetative part of plant, and its surrounding environments. All members of a population are not always in sexual reproduction stage although plants are in flowering time.

Corydalis group is divided into three sections: sect. Eucorydalis which does not have a tuber, sect. Radix-cava which has several tubers and sect. Pes-gallinaceus which has a tuber (Kim and Oh 1987b). Of these, sect. Pes-gallinaceua is perennial, and because of spring ephemeral plant, growth of tuber is very slow (Lee 1979). Morphological characters of leaf are various in the same species or change in the same plant with the growth, instead differences of several characters among the species are small (Kim and Oh 1987b). Thus, to clarify for the relationship and the phylogeny of *Corydalis* group, many studies has been carried out in systematics and many

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data accumulated presently (Kim and Oh 1987a, 1987b, 1987c, 1987d, Oh and Kim 1988, 1989, Oh *et al.* 1993). But there are few studies on population ecology of *Corydalis* group. Because this group, spring ephemeral, has a short life cycle, it is interesting to study life strategy for short growing season. And in Korea, tuber of this group has been used for oriental medical stuff for a long time. The various types of *Corydalis* in a species or among the species make troublesome to set the limits of a population in the fields, as mentioned above.

The aim of this study is to clarify whether the group composed with several closely related species of sect. Pes-gallinaceua of *Corydalis* in the same area is a population or populations ecologically. For this, studies were divided into two as follow. Firstly, a group of sect. Pes-gallinaceua of *Corydalis* was classified and analysed upon the leaf characters (Kim and Oh 1987b). And length/breadth rate, division and serration were examined for the 28 leaves spotted in front blade. The spotted leaf is specific character of *C. maculata*. Secondly, several ecological properties to clarify differences among the species were analysed. That is, specific leaf area, the number of fruit per plant and the number of seed per fruit were investigated.

MATERIALS AND METHODS

This study area is located in Sansung-ri, Joongbu-myen, Kwangju-gun, Kyonggi Province (37° 28′ 00″ N, 127° 11′ 30″ E).

The plants of sect. Pes-gallinaceua of *Corydalis* group (after this, naming *Corydalis* group) grow in the area which altitude is 150 m and a slope is easy, neighboring a small ravine. Litter and A layer is 5 ㎝ and 40 ㎝, respectively. Water and organic matter content of top soil (from surface to 10 ㎝ depth) are 20% and 15%, respectively. Rock is often come out to the surface of earth. The soil texture is loam and soil hardness is low.

The height and coverage of canopy is 17 m and 100%, respectively. Species of canopy is mainly composed of *Quercus mongolica*, *Carpinus laxiflora* and *Pinus densiflora*. Subtree layer is 6 m in height and 20% in coverage. *Styrax obtusiloba*, *Symplocos chinensis* for. *pilosa*, *P. densiflora* and *Prunus sargentii* grow in subtree layer. Shrub layer is made up of *Maackia amurensis*, *Stephanandra incisa*, *Euonymus alatus* for. *ciliato-dentatus* and 30% in coverage. Species of herb layer changes during a growing season but is mainly composed of *Disporum smilacinum*, *Hepatica asiatica*, *Viola selkirkii*, *Pseudostellaria heterophylla* and *Symplocarpus renifolius* in April and May.

The plants of *Corydalis* are randomly distributed about 400 ㎡ area. Their leaves are not piled up each other even if density is high, so that there is no competition for light (Photo 1-2). The data were got during a growth season (from March to May) in 2000.

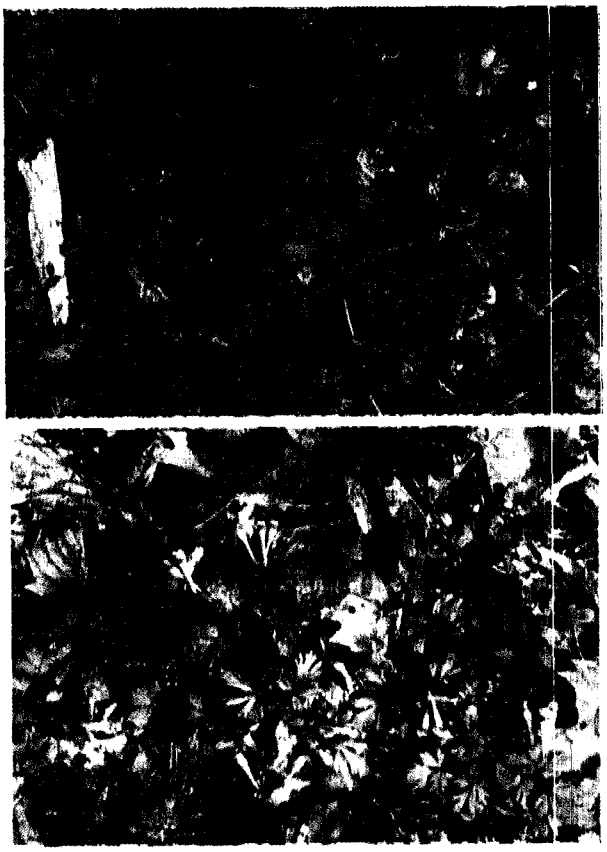


Photo 1. *Corydalis*'s distribution in the study area. The leaf types of *Corydalis* growing in narrow area are various.

Corydalis was sampled by two methods. One (leaves only) is sampled by 1 × 1 m quadrat (again divided into four 50 ㎝ × 50 ㎝ subquadrats) to check out diversity of leaf morphology in the same area on May 5, 2000. The other (total plants) is sampled 20 individuals per species to analyse the differences of several ecological properties among the species on May 10, 2000. Leaves were copied in natural color and dried in press. Identification depended on leaf morphology of dried sample and leaf copies (Kim and Oh 1987b). Because nomenclature varies depending on reporters (Lee 1979, Lee W.C. 1996, Lee Y.N. 1996, Kim and Oh 1987b), I described in *C. turtschaninovii* for *C. remota*, in *C. turtschaninovii* var. *linearis* for *C. remota* for. *lineariloba*.

The representative leaf characters were analysed for 28 individuals having conspicuously different morphology of the plants which have spots on front of leaf. Analysis was depended on characters of central leaflet, or parted central leaflet if central leaflet is again divided into leaflets having petiolule. Length and breadth of leaf blade were measured from the point which leaf blade meets petiolule to end point of serration, and the longest one, respectively. Leaf partition was divided into three types; cleft (½), parted (¾)

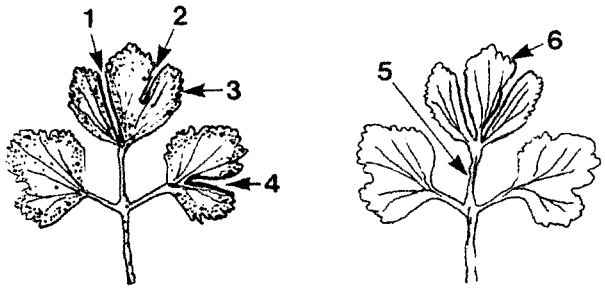


Fig. 1. Schematic diagram of leaf morphology of *Corydalis*. on May 5, 2000 in Namhansansung area. 1; divided, 2; cleft, 3; serration, 4; parted, 5; 1st central leaflet, 6; 2nd central leaflet.

confusion with serration. Easily distinguishable serrations with naked eye were only counted. Morphology of serration apex was divided into three groups: round (round, crenate), acute (serrate, ciliate, aculeate) and medium.

The samples of each species for the several ecological properties were divided into leaf, tuber and fruit, except four taxa which the number of samples was small. Specific leaf area was estimated from the data of total area (㎠) and weight (g), measured by area meter (Delta-T DIAS) and chemical balance (OHAUS), respectively, after press-drying the leaf blade. The weight of tuber was measured after drying for 48 hrs in 85℃ oven. The numbers of fruit per plant and seed per fruit were immediately counted after sampling. The significances of difference among the species were tested by t-test.

RESULTS AND DISCUSSION

The mean number of plants of sect. Pes-gallinaceua of *Corydalis* was 88.0±8.3 in 50 ㎝ × 50 ㎝ and 352±33 in 1 m × 1 m. The result that was classified along the leaf morphology was as shown in Table 1. Total eight species or varieties were identified.

Of the 352 plants, the number of *C. turtschaninovii* was the most

Table 1. The number of plants for each species in 1 m × 1 m quadrat on May 5, 2000 in Namhansansung area

Species	Number of plant (Rate)
C. ambigua	78 (22.2%)
C. turtschaninovii	103 (29.3%)
C. turtschaninovii var. *linearis*	22 (6.3%)
C. turtschaninovii var. *pectinata*	58 (16.5%)
C. turtschaninovii var. *genuina*	10 (2.8%)
C. turtschaninovii var. *rotundiloba*	11 (3.1%)
C. turtschaninovii var. *fumariaefolia*	9 (2.6%)
C. maculata	61 (17.3%)
Total	352

with 103(29.3%), and that of *C. ambigua* was the next with 78 (22.2%), and that of *C. turtschaninovii* var. *fumariaefolia* was the smallest with 9(2.6%). Therefore, the number of *C. turtschaninovii* taking varieties together was 213(60.5%). But there were many plants that were indistinguishable among the species or variety, and conspicuous difference between first and second leaf. Especially, leaf shape, leaf margin and leaf spot changed gradually along the plants. By these variation, Kim and Oh (1987b) pointed out that it was difficult to classify *Corydalis* group into species or variety on the leaf morphology.

Of the plants spotted on the front of leaf, leaves of 28 plants which had representative morphology were as shown in Fig. 1. The spots on the front of leaf are typical character of *C. maculata*. The arrangement order was according to the extent of division of central leaflet, but this changed along the character. Roughly, there were No. 5, No. 24 and No. 25 in plant of *C. ambigua*, No. 16, No. 19, No. 23 and No. 28 in *C. turtschaninovii*, No. 10 in *C. turtschaninovii* var. *liearis*, No. 15, No. 20 and No. 27 in *C. turtschaninovii* var. *genuina*, No. 2 and No. 3 in *C. turtschaninovii* var. *rotundiloba*, and No. 13 in *C. maculata*. The remainders could not be belonged to a species or variety. By this fact, it was supposed that identification for *C. maculata* was wrong, or that hybrids formed among the species. It was thought that the latter might be more possible.

For these 28 plants, several qualitative characters of leaf morphology were shown in Table 2. Firstly, central leaflet was one or parted again. In case of central leaflet parted, the extent of partition was various, but the number of partition was one or two. In the most parted plants, parted leaflet had petiolule, so that central leaflet was composed of three parted leaflets. Therefore, central leaflet appeared from 1 leaflet to 3 parted leaflets. Cleft, parted and lobed types appeared to the extent of partition. By this result, it was thought that partition types of central leaflet changed with order of 0 (no parted) → ½ (one cleft) → ¾ (one parted) → ① (one divided) → ¾+¾ (two parted) → ¾+① (one parted, one divided) → ①+① (two divided) → ½+2 (one cleft, two leaflets) → ¾+2 (one parted, two leaflets) → ①+2 (1 divided, two leaflets) → 3 (three leaflets) in this study area. Of course, all medium steps existed in datum analysed for 352 plants. The partition of central leaflet thus changed gradually and there was no precise border in this character among the species or varieties. Kim and Oh (1987b) reported that basic leaf type of *Corydalis* group is triternate (central leaflet composed of three leaflets). But other types except for triternate appeared many plants in this study and leaf types of *Corydalis* group were thought to be unstable character.

Secondly, length/breadth rates (L/B rate) of central leaflet were various from 0.79 to 2.17 (mean±SD = 1.26±0.32). The integrating result of the L/B rate that 28 plants was divided into several

groups along the extent of partition was as shown in Table 3. The L/B rate was 1.24±0.30 in non-parted plants (No. 1~No. 14), 1.39 ±0.25 in one parted plants (No. 15~No. 18), 0.91±0.07 in two parted plants (No. 19~No. 23), and 1.48±0.17 in three leaflet plants (No. 25~No. 28). Therefore, the L/B rate was the lowest in two parted leaflet and the highest in three leaflets. The leaf types were roughly fan shape. But types of non-parted or one parted leaflet were various and those of two parted one were a diamond shape and those of three leaflets were long. And L/B rate had no relation to the extent of leaf partition.

Thirdly, serrations distributed in leaf apex and its sizes were various. Serration types were serrate and double serrate. The numbers of serration were in wide range of 3~23 (mean±SD = 11.15 ±6.76). The numbers of serration was 10.29±6.81 in non-parted plants (No. 1~No. 14), 12.50±5.50 in one parted plants (No. 15~ No. 18), 18.60±2.58 in two parted plants (No. 19~No. 23), and 6.25±2.16 in three leaflet plants (No. 25~No. 28). Therefore, the number of serration increased with the extent of partition. The reason why the number of serration was small in plants which were divided into three leaflets again, was thought to be considered the central parted leaflet only.

The types of serration were divided into round, medium and acute. This character was various regardless of other characters and no constant trend with the species or variety.

Therefore, it was thought that it was difficult to divided *Corydalis* group living in same area into species or variety by leaf characters, e.g. the extent of partition, number of leaflets, leaf margin (serration). The reason was that these characters changed gradually or had no relation to species, as in case of central leaflet of the plants which had spots on the leaf front, *C. maculata*.

Specific leaf area (SLA), the number of fruits per plant, and the number of seed per fruit in each species were as shown in Table 4. Dry weight of tuber was 0.4~1.5 g and differences between species was not significant. Relationship between the number of fruit or seed and tuber weight would be reported later.

Value of SLA was 120~532 in all plants and mean values of each species were in the range of 359~412. Differences among the species were not significant. This value was smaller than that of *Arisaema rotundifolia* of 425 (Min, 1997), but larger than *Symplocarpus renifolius* of 350 (Min and Kang 1994) or *Heleniopsis orientalis* of 332 (Min 2000), and these species are the shaded plants which grow in the vicinity. Therefore, the SLA value of *Corydalis* was in the range of other shaded plant species. Because that SLA value varies in the same plant along the extent of irradiation or plant growth, this datum is not characteristic of a species (Evans 1972).

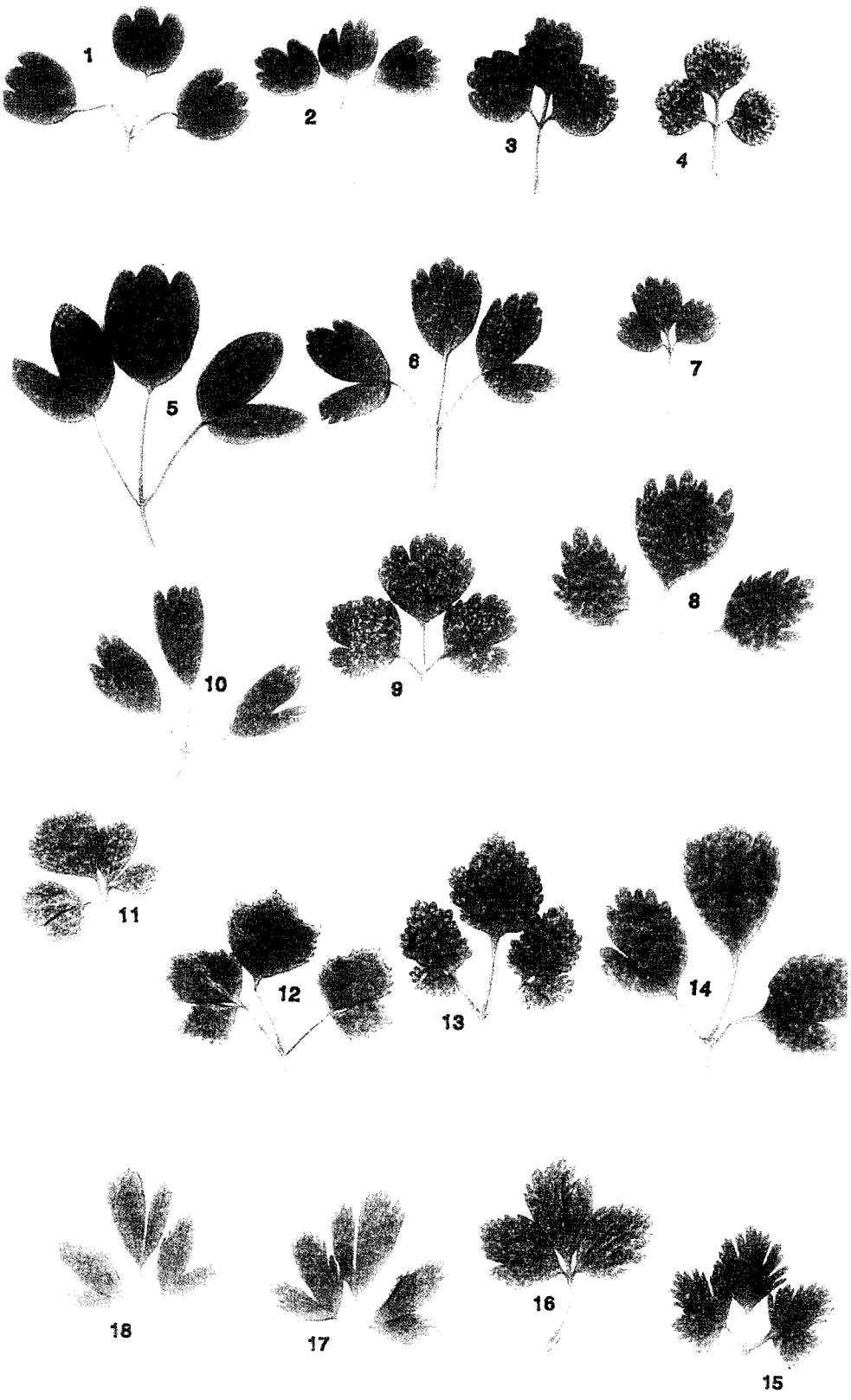
The number of fruit per plants was in the range of 1~12. And

Table 2. Properties of central leaflet shown in Fig. 1

No. of plate	No. of leaflet	Status of division	Length/ breadth	No. of serration	Type of serration
1	1	0	1.06	3	medium
2	1	0	1.21	4	round
3	1	0	1.11	5	round
4	1	0	0.88	9	round
5	1	0	1.35	3	round
6	1	0	1.47	7	medium
7	1	0	1.15	6	round
8	1	0	1.21	11	medium
9	1	0	1.00	14	medium
10	1	0	2.17	4	acute
11	1	0	1.05	17	acute
12	1	0	1.09	23	medium
13	1	0	1.17	23	medium
14	1	0	1.48	15	rounc
15	1	½	1.10	21	medium
16	1	¾	1.59	10	medium
17	1	¾	1.19	13	acute
18	1	1	1.69	6	acute
19	1	¾, ¾	0.86	16	medium
20	1	¾, 1	1.00	17	acute
21	1	¾, 1	0.96	23	medium
22	1	1, 1	0.79	20	round
23	1	1, 1	0.93	17	medium
24	2	½	1.87	3	acute
25	3	0	1.67	3	round
26	3	0	1.25	6	round
27	3	0	1.38	7	acute
28	3	0	1.61	9	medium

Table 3. Length/breadth rates and the number of serration along the number of leaflet or division on May 5, 2000 in Namhansansung area (n=28)

No. of leaflet	No. of partition	Length/breadth	No. of serration
1	0	1.24±0.30	10.29±6.81
1	1	1.39±0.25	12.50±5.50
1	2	0.91±0.07	18.60±2.58
3	0	1.48±0.17	6.25±2.16
mean±SD		1.26±0.32	11.25±6.76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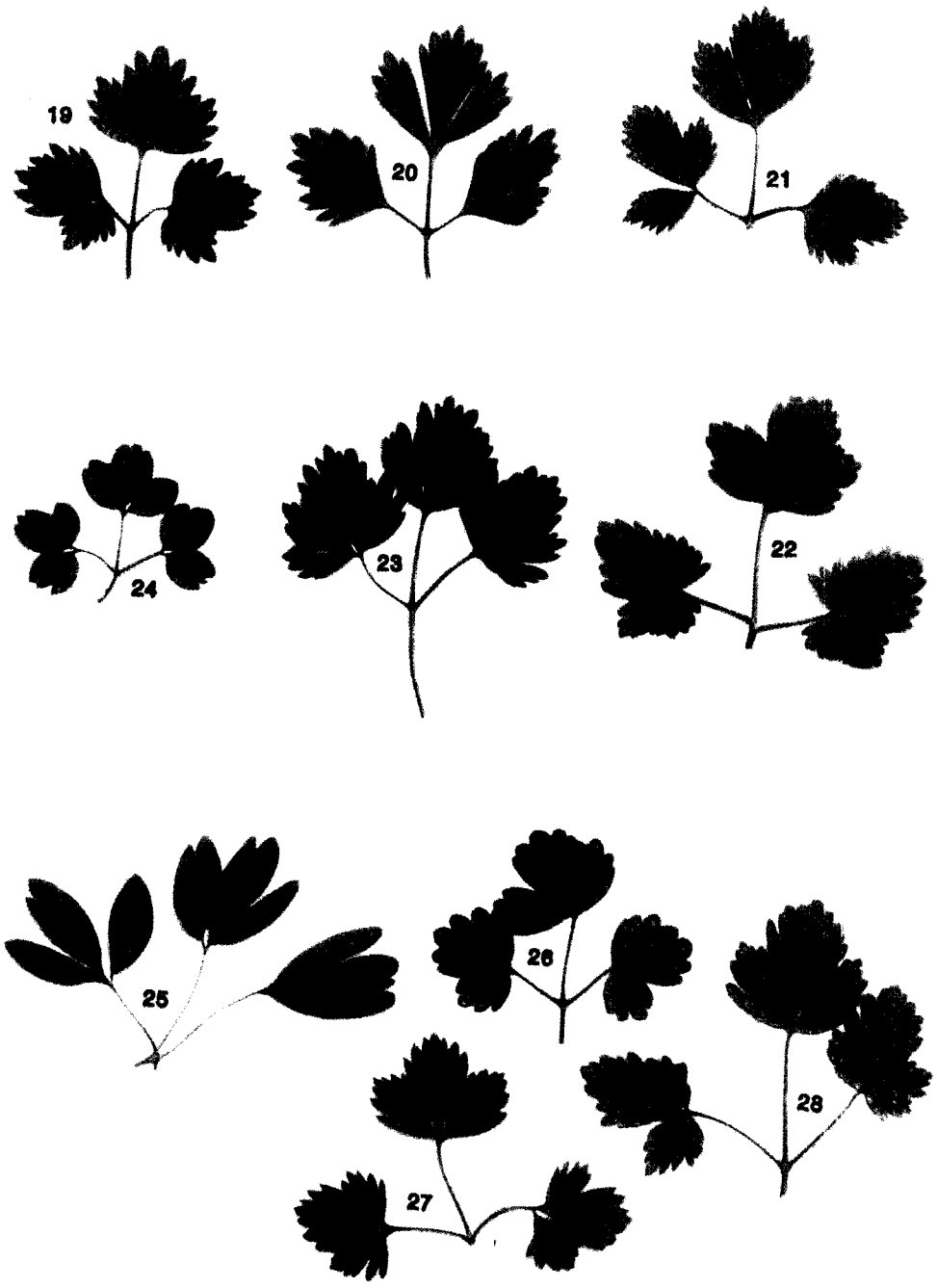

Photo 2. The leaf types of *Corydalis* in the study area.

Table 4. Specific leaf area, fruit number per plant and seed number per fruit in each species of *Corydalis* group on May 10, 2000 in Namhansansung area (n=20) (mean±SD)

Species	Specific leaf area (㎠/g)	No. of fruit per plant	No. of seed per fruit
C. ambigua	412±233	5.3±2.9	5.7±4.4
C. turtschaninovii	359±201	3.9±3.3	6.0±5.5
C. turtschaninovii var. *pectinata*	371±299	4.1±3.6	5.9±5.1
C. maculata	385±277	3.6±3.0	7.1±5.9

mean number of fruit in each species was from 3.6 (*C. maculata*) to 5.3 (*C. ambigua*). The number of fruit number was various in the same species along each plant. The difference of fruit number per plant between species was not significant.

The number of seed per fruit was in the range of 1~16. And the mean number of seed in each species was from 5.7 (*C. ambigua*) to 7.1 (*C. maculata*). The difference of seed per fruit number between species was not significant. On the whole, the number of fruit per plant was in inverse proportion to that of seed per fruit. By this result, it was thought that seeds produced per plant were relatively limited. Generally, shaded plant species produce seeds which are large in size and small in number (Silvertown 1982). It was thought that *Corydalis* group belonged in shaded plant species.

CONCLUSION

The aim of this study is to clarify whether closely related species living in the same area is regarded as a population ecologically or not. This study was carried out in the natural *Corydalis* group. This group has the properties as follow.

Firstly, all members of *Corydalis* group live in same area. That is, the plants of *Corydalis* group are randomly distributed in the area of 400 ㎡. Three hundred fifty two plants exist in the sampling site of one square meter (1m × 1m quadrat). Therefore, it is thought that the microhabitat (air temperature and soil properties) is similar in the sampling site. By Harper *et al.*(1961), the same area means that ecological condition is same and struggle for existence can reasonably be considered possible, and for co-existence of closely related species in the same area, each species must demand its own different microenvironment and the intensity of struggle for existence be weak. Each member of community or population in the same area lives under different condition with others, if precisely examined the microenvironment. This is the reason why organisms which had similar ecological niche must not be co-existence (Harper *et al.* 1961). The density of the closely related species living in the same area is maintained in the proper level (Harper *et al.* 1961). In this study area, it was not ascertained that competition was happening among the plants by density. But by the fact that leaves did not overlap each other, it was thought that there was no competition for sun light.

Secondary, *Corydalis* mainly increased by sexual reproduction. Of the genus *Corydalis*, the sect. Pes-gallinaceus has a perennial tuber, which can not reproduce vegetatively (Kim and Oh 1987b). As mentioned above, various species grow in the short range that pollination by insect is possible. But it is not identified that as the result of interbreeding between species hybrids are fertile. Generally, if sexual barrier is imperfect, sterile or fertile hybrids are easily formed by interbreeding (Harper *et al.* 1961). It is interesting to estimate whether many closely related species come into the same area by chance or one species differentiates into many species in the same area. Speciation mainly are made from sympatric and allopatric mechanism (Harper *et al.* 1961). As the former, the co-existence of closely related species is the result of diversification under other species in the same area. And it is possible that the closely related species which are geographically isolated come into the same area. But in field, it is difficult to discriminate these two results (Harper *et al.* 1961).

The morphological and ecological properties of *Corydalis* group were abstracted as follow. Firstly, morphological characteristics were various in a species and changed gradually. The properties of each species overlapped and were no sharp borderline with other species' one. The classification result on a property was not coincided with that on other one. The fact that leaf characters are various was already reported by Kim and Oh (1987b). Especially, spotted leaf is a distinguishing trait of *C. maculata* but, in this study, other species (*C. ambigua, C. turtschaninovii, C. turtschaninovii* var. *pectinata*, etc) have the spotted leaves. And the number or the extent of clearness of spot varied with each plant. This fact might be resulted from interbreeding as mentioned above. And this made to classify *Corydalis* group into species difficult in the ecological field survey.

At the time of field survey, all members of a population does not have always sexual organ.

Therefore, *Corydalis* group might be regarded as a population in this study. This reason was due to the possibility of interbreeding among the *Corydalis* group living in the same area, and the reality of setting the limit of a population in ecological survey.

Secondary, several ecological properties among the species of *Corydalis* group were indifferent. This fact might be resulted from that this plants are spring ephemeral and their life strategy is sensitively affected by physical environment in the spring (Cho 1998). As reported later, the shoot germination of *Corydalis* is related to the thawing of soil in the early spring, so that the difference of ecological properties of *Corydalis* group is resulted from environmental factors rather than intrinsic species' strategy. In *Viola*, under natural field conditions, environment is a more important factor in determining the ecological properties than genetic differences among individuals (Solbrig 1981).

Summarizing above-mentioned, it is thought that *Corydalis* group is regarded as a population in ecological study. After this, it is prerequisite that the category of species (variety) or interrelationship among the taxa are systematically put in order for this group by molecular biological analysis. And to clarify the extent of fertility for the seeds reproduced by interbreeding is needed.

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