

First Report of *Asplenium yoshinagae* (Aspleniaceae) from Korea and Its Phylogenetic Position Based on Morphology

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Asplenium yoshinagae (Aspleniaceae), previously known only from Japan, southwest China to Himalaya, was found in Gageo-do, Heuksan-myeon, Sinan-gun, Jeollanam-do. This species is similar to *A. trichomonas*, *A. tripteropus*, *A. boreale*, *A. normale* and *A. oligophlebium* by having gemmae and auricle of pinna, and distinguished from the latter by distinct stipe length, stalk of pinna, acute apex of pinna, length of indusium and shape of sorus. The Local name, Ga-geo-kko-ri-go-sa-ri, was newly given considering the locality. To reveal the interspecific relationships within the genus *Asplenium* in Korea, cladistic analysis was performed for 22 taxa of *Asplenium* as ingroup and 2 taxa of *Diplazium* as outgroup from Korea based on 20 morphological characters. As the results, the genus *Asplenium* separated strongly from outgroup, and divided into 4 clades. *Asplenium yoshinagae* belong to the third clade. *A. hondoense* N. Murakami & S. I. Hatanaka, which contained in the second clade, had treated as *Hymenasplenium*, but this results supported that this taxon may be contained in *Asplenium*, and also, *Asplenium ruprechtii*, not in *Comptosorus*. The morphological characters and illustrations of the species are provided together with photographs of habitat.

Keywords: Aspleniaceae, *Asplenium yoshinagae*, first report, Korea, taxonomic position

The family Aspleniaceae comprise, a single and extremely diverse genus *Asplenium*. The genus *Asplenium* contains about 700 taxa and widely distributed in the world (Iwatsuki, 1995; Wagner *et al.* 1993). The genus *Asplenium* have been treated as several genera, *Camptosorus*, *Phyllitis*, *Ceterach*, and *Pleurosorus* by the characters of leaf vein and sori arrangement (Tagawa, 1959; Park, 1975; Lee, 1980). Otherwise, this genus divided into

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two genera or sections, *Hymenasplenium* and *Asplenium* by the character of rhizome (Hayata, 1927; Iwatsuki, 1975). But, a satisfactory taxonomic division into subgenera or satellite genera has not been possible because of the absence of any significant gaps (Wagner *et al.*, 1973) and numerous intergeneric hybrids were reported (Morton, 1956; Prada, *et al.*, 1995). The genus *Diplazium* which contained in the family Athyriaceae, had been treated as the genus *Asplenium* by gone days, because of similar character in sorus shape, oblong or linear and indusium margine, entire (Tagawa, 1959; Iwatsuki, 1995).

The members of the genus *Asplenium* of Korea have been known as 21 taxa (Lee, 2006). However, *Asplenium yoshinagae* Makino was collected from Gageo-do, Heuksan-myeon, Sinan-gun, Jeollanam-do. *Asplenium yoshinagae* has known to distribute in warm regions of Japan and China. Gageo-do island is the most southwest location of Korea. This taxon is almost gemmiferous at the base of pinna stalk on the upper side of the rachis, somewhat thin pinna, and its ultimate segments of pinna cut into narrower teeth. This species is closely related *A. planicaule* Wall. from North India, China, and Taiwan by having pinnated fronds, petiolated pinna and acute pinna apex, but is different from the latter having no gemma at rachis and somewhat thick pinna (Tagawa, 1951).

We first report *Asplenium yoshinagae* for Korea with new Korean local name, and reveal the taxonomic position of *A. yoshinagae* among 22 Korean *Asplenium* taxa based on morphological characters.

Materials and Methods

Asplenium yoshinagae Makino (Figs. 1 & 2) were collected first in Korea and the voucher specimens are deposited in Ewha Womans University Herbarium (EWH). To reveal the taxonomic position of *A. yoshinagae*, 20 morphological characters (Table 1) referred to the flora and illustrated books (Tagawa 1959; Li *et al.*, 1975; Nakaike, 1975; Ohwi, 1984; Iwatsuki, 1992; Iwatsuki *et al.*, 1995; Lee, 2006) for 22 taxa of Korean *Asplenium* and two taxa of *Diplazium* as outgroup were coded for cladistic analysis (Table 2).

Morphological data matrix were analyzed using both maximum parsimony methods available in PAUP* 4.01b (Swofford, 2002). For the maximum parsimony analysis, TBR branch swapping, with MULPARS and STEEPEST DESCENT, were employed. For the analysis of morphological characters, weights were assigned to all characters such that minimum possible length of each character was as close to 1000 as possible. Thus binary

Table 1. Morphological characters used in the cladistic analysis for 22 taxa of the genus *Asplenium* as ingroup and 2 taxa of *Diplazium* as outgroup.

Characters	Character state
1 Sprouting of frond from rhizome	fascicled (2), adjacent (1), sparse (0)
2 Stipe length	less than 10 cm (0), more than 10 cm (1)
3 Scale margin	entire (0), toothed (1)
4 Pinnation of frond	simple (0), 1 pinnated (1), more than twice pinnatifid (2)
5 Shape of frond	linear or lanceolate (0), deltoid or oblong (1)
6 Ratio of width/length of pinna	no pinnae (0), less than 1/3 (1), more than 1/3 (2)
7 Stalk length of pinna	no pinnae (0), less than 2 mm (1), more than 2 mm (2)
8 Shape of pinna	no pinnae (0), lanceolate or oblong-lanceolate (1), oblong-subdeltoid (2), oblong or oblong-ovate (3)
9 Apex of pinna	no pinnae (0), shallowly acuminate (1), long acute (2)
10 Stalk length of pinnule	no pinnule (0), 0 to 1 mm (1), more than 1 mm (2)
11 Ratio of width/length of pinnule	no pinnule (0), less than 1/3 (1), more than 1/3 (2)
12 Margin of pinnule segment	no pinnule (0), crenate or lobed (1), pinnatifid (2)
13 Overlapping pinnules	no pinnule (0), never overlap (1), overlap (2)
14 Auricle of pinnae or pinnule	no pinnae or pinnule (0), absent (1), present (2)
15 Length of indusium	less than 1.5 mm (0), 1.5–3 mm (1), more than 3 mm (2)
16 Shape of sorus	oblong (0), linear (1)
17 Presence of gemma	absent (0), present (1)
18 Wing of perispore	narrow (0), broad (1)
19 Scale surface pattern	absent (0), clathrate (1)
20 Sori arrangement along midrib	singled (0), paired (1)

characters were assigned a weight of 1000, three-state characters a weight of 500, four-state characters a weight of 333 (Lee *et al.*, 2001). The data analyzed using MP and the heuristic search and apomorphic characters in each node described above, and bootstrap strategies described below. Subsequently distance trees were constructed by using neighbor-joining.

Description and Discussion

Asplenium yoshinagae Makino Phan. Pter. Jap. Icon. 1: t. 64 (1900)

Korean name: Ga-geo-kko-ri-go-sa-ri (가거꼬리고사리)

Plants on rock, evergreen fern of medium size; rhizome short, ascending to erect, densely scaly; scales lanceolate, elongate at apex, entire, to 4–5 mm long, 0.5–0.6 mm wide, dark brownish to blackish. **Stipes** erect, 10–15 cm long, dark green to brownish

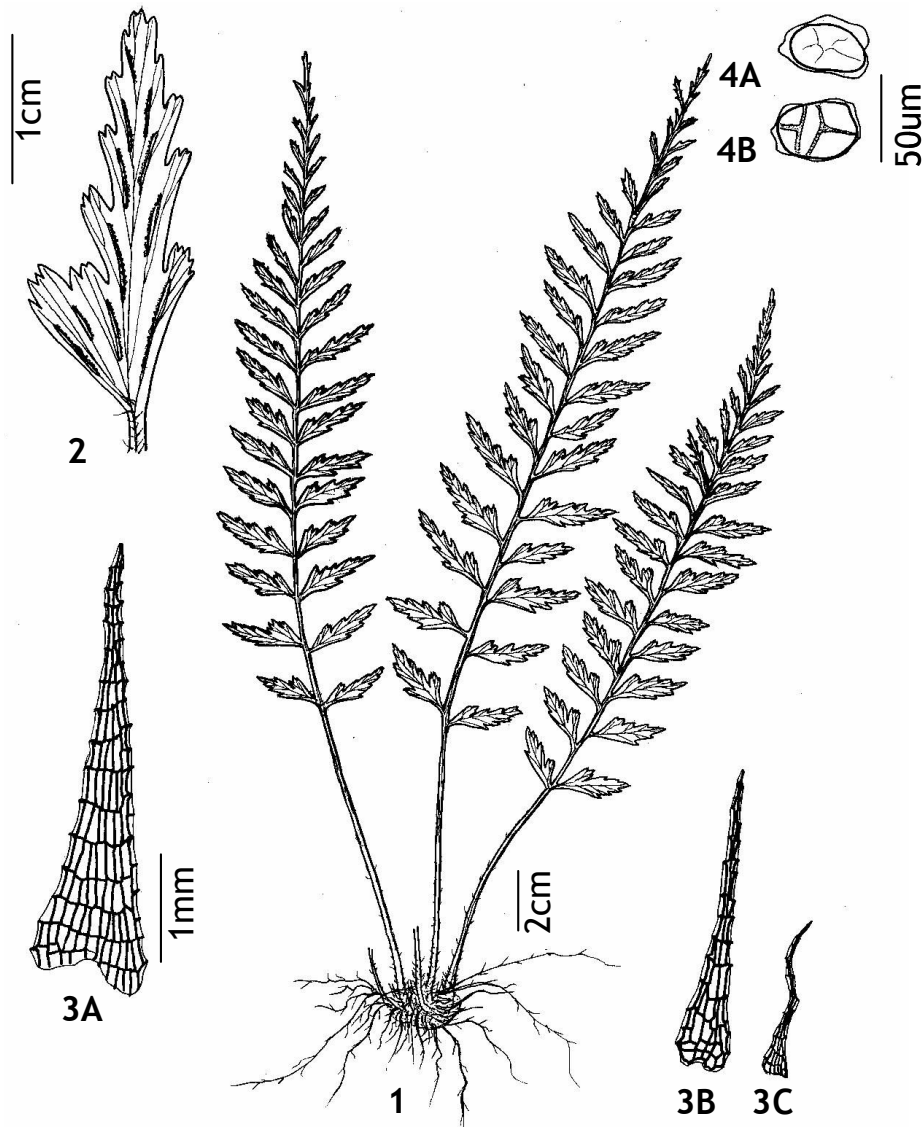


Fig. 1. *Asplenium yoshinagae* Makino. 1. Habit, 2. Pinnae, 3. Scales (A: on rhizome, B: on stipe, C: on rachis), 4. Spores (A: polar view, B: lateral view).

gemmiferous at junction of rachis and pinna rachis; pinnae 12-25 pairs, stalk 2 mm long, irregularly rhomboid, acute at apex, more or less auricled at acroscopic and cuneate at basiscopic bases; pinna lobed moderately to deeply; lobes dentate. **Sori** and **indusia** ascending along midrib, lanceolate, 3-7 mm long. **Sporangia** with stalk of 1 row of cells,



Fig. 2. Photograph of *Asplenium yoshinagae* Makino (Gageo-do, Oct. 3, 2007).

Table 2. Matrix of morphological data for 22 taxa of the genus *Asplenium* and two taxa of *Diplazium* as outgroup in Korea. Character numbers are shown in Table 1.

Taxa / Characters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
<i>A. wrightii</i>	2	1	1	1	1	2	1	1	2	0	0	0	0	1	2	1	0	1	1	1
<i>A. shikokianum</i>	2	1	1	2	1	2	1	1	2	0	0	0	0	1	2	1	0	1	1	1
<i>A. tenerum</i>	2	1	1	1	0	2	1	1	1	0	0	0	0	1	2	1	0	1	1	1
<i>A. hondoense</i>	0	1	1	0	0	2	1	1	1	0	0	0	0	1	2	1	0	1	1	1
<i>A. yoshinagae</i>	2	1	0	1	0	1	2	3	2	0	0	0	0	2	2	1	1	1	1	1
<i>A. oligophlebium</i>	2	0	0	1	0	1	1	2	1	0	0	0	0	2	0	0	1	1	1	1
<i>A. normale</i>	2	0	0	1	0	1	1	2	1	0	0	0	0	2	0	0	1	1	1	1
<i>A. boreale</i>	2	0	0	1	0	1	1	2	1	0	0	0	0	2	0	0	0	1	1	1
<i>A. tripteropus</i>	2	0	0	1	0	1	1	3	1	0	0	0	0	2	0	0	1	1	1	1
<i>A. trichomanes</i>	2	0	0	1	0	1	1	3	1	0	0	0	0	2	0	0	1	1	1	1
<i>A. prolongatum</i>	2	1	1	2	0	1	1	3	1	1	1	1	1	1	2	1	1	1	1	1
<i>A. ritoense</i>	2	1	1	2	1	1	2	3	2	2	2	2	2	1	1	0	0	1	1	1
<i>A. wilfordii</i>	2	1	0	2	1	1	2	3	2	2	2	2	2	1	1	0	0	1	1	1
<i>A. varians</i>	2	0	0	2	1	1	2	3	1	1	2	2	2	1	1	0	0	1	1	1
<i>A. incisum</i>	2	0	0	2	1	1	1	3	1	1	2	2	2	1	1	0	0	1	1	1
<i>A. pekinense</i>	2	0	1	2	1	1	2	3	1	2	2	2	1	1	1	1	0	1	1	1
<i>A. ruta-muraria</i>	2	0	1	2	1	1	2	3	1	1	2	1	1	1	1	1	0	1	1	1
<i>A. sarelii</i> var. <i>sarelii</i>	2	0	0	2	1	1	2	3	1	2	2	2	2	1	1	1	0	1	1	1
<i>A. sarelii</i> var. <i>anogrammoides</i>	2	0	0	2	1	1	2	3	1	1	2	2	1	1	1	1	0	1	1	1
<i>A. scolopendrium</i>	2	1	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	1	1	1
<i>A. antiguum</i>	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	1	1	1
<i>A. ruprechtii</i>	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
<i>D. subsinuatum</i>	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
<i>D. wichurae</i>	0	1	0	1	1	2	1	1	2	0	0	0	0	0	0	1	0	0	0	0

black, not bright, scaly. **Laminae** lanceolate, acute to acuminate, once pinnate, commonly 18–20 cm long (rarely 40 cm long), 5 cm wide; thick but not stiff, glabrous, deep green; annuals vertical, interrupted by sporangial stalk. **Spores** monolete, perispore typically winged.

Distribution: Korea, Japan, China to Himalaya.

The new local name: 'Ga-geo-kko-ri-go-sa-ri' was given considering the collection locality, Ga-geo island, where is located in the most southwestern Korea, and closest from Philippine and China. It was first found on the rock with *Crepidomanes minutum* at the lower edges of Doksil-san in Gageo-do, Heuksan-myeon, Sinan-gun, Jeollanam-do on October 3, 2007.

Maximum parsimony analysis of 20 morphological characters resulted in 25 trees. Bootstrap estimates were supported by values 55–93%. The neighbor-joining trees showed a similar patterns in which the taxa are grouped together. The phylogenetic tree with accompanying bootstrap value and apomorphic character, is presented in Fig. 3.

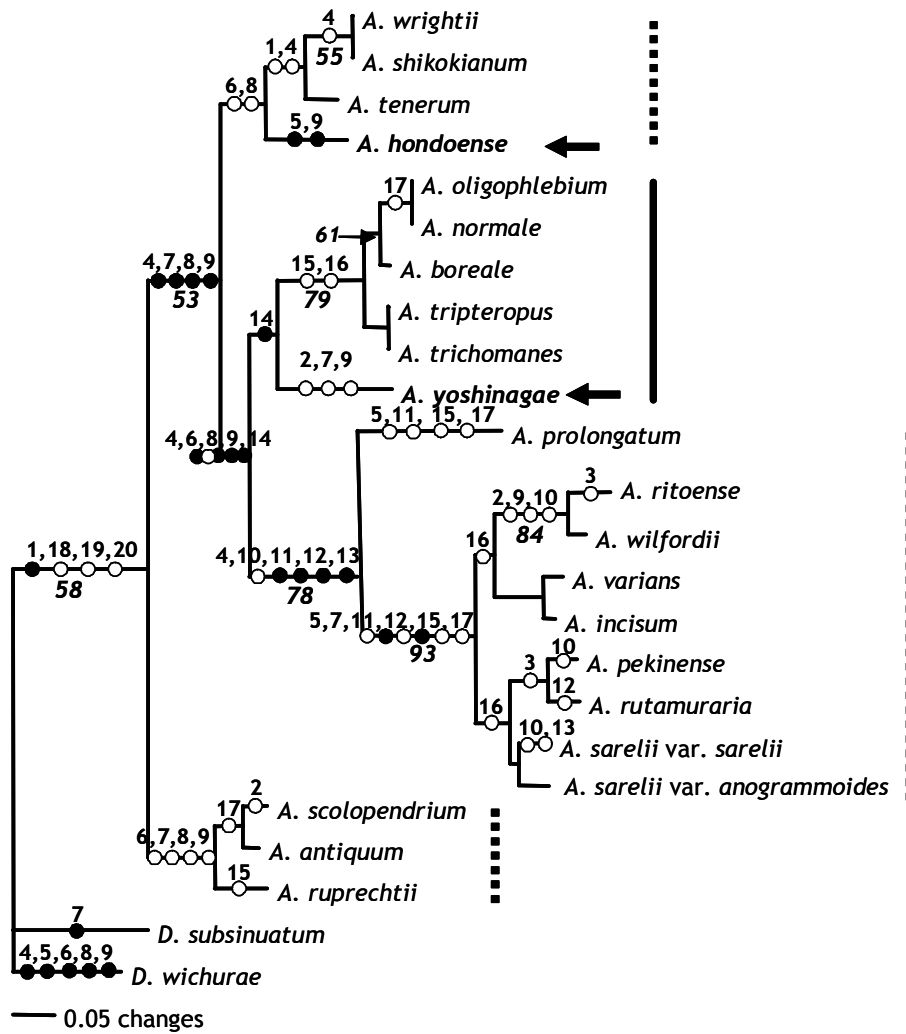


Fig. 3. Phylogenetic tree for 22 taxa of the genus *Asplenium* from Korea, and 2 taxa of *Diplazium* as outgroup based on 20 morphological characters. Apomorphic characters and bootstrap percentages are provided above and below each branch, respectively. Black circles represent nonhomoplastic synapomorphies and white circles represent homoplastic synapomorphies.

Asplenium yoshinagae formed monophyletic clade with *A. trichomanes*, *A. tripteropus*, *A. boreale*, *A. normale* and *A. oligophlebium* by homologous character (character 14: presence of auricle in pinnae or pinnule), It suggests that these 5 taxa were more similar

with *A. yoshinagae* among the taxa of *Asplenium* in Korea. While, *A. yoshinagae* was separated from these 5 taxa by five characters (stipe more than 10 cm long in character 2; stalk of pinnae distinct in character 7; pinnae apex acute in character 9; indusium more than 3 mm in character 15; sori linear in character 16). *Asplenium yoshinagae* is distinguished from *A. tripteropus* and *A. trichomanes* by having moderately to deeply divided of pinna margin.

Within 22 taxa examined, *A. yoshinagae* is most similar with *A. planicaule* Wall. from North India by having stipe and rachis dull brown, pinna without a costa, and it was treated as *A. planicaule* var. *yoshinagae* (Mak.) Tagawa com. nov. by Tagawa (1951) as synonym. *Asplenium yoshinagae* is almost always gemmiferous at the base of pinna stalk on the upper side of the rachis, somewhat thinner in the texture, and its ultimate segments of pinna cut into narrower teeth, but *A. planicaule* is never gemmiferous at rachis and texture somewhat thicker. Therefore, we here followed *A. yoshinagae* Makino as a species, not *A. planicaule* var. *yoshinagae* (Mak.) Tagawa (Iwatsuki, 1992, 1995), but it will be elucidated more when the another analysis as like anatomy, molecular approach etc. is accompanied.

The cladistic tree of 22 taxa of Korean *Asplenium* based on the 20 morphological characters showed that four monophyletic clades within the tree. First clade consisted *A. scolopendrium*-*A. antiquum*-*A. ruprechtii* by having four homologous characters (character 6: ratio of width/length of pinna; character 7: stalk length of pinna; character 8: shape of pinna; character 9: apex of pinna). Second clade consisted *A. hondoense*-*A. wrightii*-*A. shikokianum*-*A. tenerum* by having two homologous characters (character 6: ratio of width/length of pinna; character 8: shape of pinna). Third clade consisted *A. yoshinagae*-*A. oligophlebium*-*A. normale*-*A. boreale*-*A. tripteropus*-*A. trichomanes* by having one homologous character (character 14: auricle of pinna), and fourth clade formed *A. prolongatum*-*A. ritoense*-*A. wilfordii*-*A. varians*-*A. incisum*-*A. pekinense*-*A. rutamuraria*-*A. sarelii* by having five homologous characters (character 4: pinnation of frond; character 10: stalk length of pinnule; character 11: ratio of width/length of pinnule; character 12: margin of pinnule segment; character 13: overlapping pinnule).

In the second clade, *A. hondoense* N. Murtakami & S. I. Hatanaka (syn. *A. unilaterale* Lam.) was transferred from the genus *Asplenium* to the genus *Hymenasplenium* by characters of long creeping rhizome by Hayata (1927). But this cladistic tree, analyzed by 20 morphological characters, showed monophyletic clade (Fig. 3) with *A. wrightii*, *A. shikokianum* and *A. tenerum* by homologous characters (character 6: ratio of width/length

of pinna; character 8: shape of pinna). This result supported that *A. hondoense* belongs to the genus *Asplenium*, not *Hymenasplenium*. *Asplenium scolopendrium* L. used in *Phyllitis scolopendrium* (L.) Newman for a time, (Tawaga, 1959; Park, 1975), but grouped monophyletic clade with *A. antiquum* by similar character (character 15: length of indusium; character 17: gemma absent). These phylogenetic tree supported *A. scolopendrium* L. (Iwatsuki, 1995; Lee, 2006) instead of *Phyllitis scolopendrium* (L.) Newman.

Asplenium ruprechtii Sa Kurata treated as a member of genus *Comptosorus* as well as the American sister species, *A. rhizophyllum*, based on reticulate venation, but only one character is not enough to affiliate its genus and these species easily hybridize (Iwatsuki, 1995). This phylogenetic tree showed that *A. ruprechtii* grouped with *A. scolopendrium* and *A. antiquum* by four homologous characters (character 6: ratio of width/length of pinna; character 7: stalk length of pinna; character 8: shape of pinna; character 9: apex of pinna), and supported *A. ruprechtii* Sa Kurata (Iwatsuki, 1992, 1995; Lee, 2006) as a member of genus *Asplenium*.

Asplenium yoshinagae Makino can be distinguished from the related taxa of the genus *Asplenium* in Korea as following:

1. Laminae simple, leaf margin almost entire.
 2. Leaf veins all free *A. scolopendrium*
 2. Leaf veins reticulate, forming areoles or uniting veinlets in leaf margin.
 3. Lateral veinlets divided pinnately, forming 1-4 areoles, with gemmae at leaf apex *A. ruprechtii*
 3. Lateral veinlets simple, divided by Y-shape, parallel to leaf margin, united by marginal veinlets, without gemmae at leaf apex *A. antiquum*
1. Laminae pinnated 1-4 times.
 4. Laminae pinnated 1-2 times.
 5. Pinnae lanceolate or oblong-lanceolate, pinnae length/width more than 3 times; rachis without gemmae.
 6. Rhizome short, erect.
 7. Pinnae lanceolate, acuminate to caudate at apex, rachis without wing.
 8. Laminae pinnated once *A. wrightii*
 8. Laminae pinnated twice *A. shikokianum*
 7. Pinnae oblong-lanceolate, obtuse at apex, rachis with wing *A. tenerum*

6. Rhizome long, creeping *A. hondoense*
5. Pinnae broadly oblong, oblong, oblong-subdeltoid, pinnae length/width less than 3 times; rachis with gemmae.
9. Stipe more than 10 cm; pinnae stalk distinct, pinnae apex acute
..... *A. yoshinagae*
9. Stipe less than 10 cm; pinnae stalk no, pinnae apex shallowly acuminate.
10. Pinnae oblong-subdeltoid.
11. Pinnae incised more than half way to midrib; auricles distinct
..... *A. oligophlebium*
11. Pinnae shallowly incised; auricles indistinct.
12. Pinnae oblong, rachis gemmiferous *A. normale*
12. Pinnae broadly oblong, rachis no gemmiferous *A. boreale*
10. Pinnae oblong or oblong-ovate.
13. Three wings on stipe and rachis *A. tripteropus*
13. Two wings on stipe and rachis *A. trichomanes*
4. Laminae more 2 pinnate.
14. Laminae linear lanceolate, length/width of pinnule less 3, indusium more 3 mm long, rachis gemmiferous *A. prolongatum*
14. Laminae deltoid or oblong, length/width of pinnule more 3, indusium 1.5-3 mm long, rachis no gemmiferous.
15. Sori oblong.
16. Stipe more 10 cm long, pinnae apex long acute, pinnule stalk length more 1 mm.
17. Scale margin toothed *A. ritoense*
17. Scale margin entire *A. wilfordii*
16. Stipe less 10 cm long, pinnae apex shallowly acuminate, pinnule stalk length 0-1 mm.
18. Stipe green, frond monomorphic, pinnae stalk length more than 2 mm
..... *A. varians*
18. Stipe purplish green, frond subdimorphic, pinnae stalk length less than 2 mm *A. incisum*
15. Sori linear.
19. Scale margin toothed.
20. Pinnule stalk more than 1 mm long, pinnule margin pinnatifid
..... *A. pekinense*
20. Pinnule stalk 0-1 mm long, pinnule margin crenate or lobed

- *A. ruta-muraria*
19. Scale margin entire.
21. Laminae 10-20 cm long, indusium 1.5-3 mm long
- *A. sarelii* var. *sarelii*
21. Laminae less than 10 cm long, indusium 1-1.5 mm long
- *A. sarelii* var. *anogrammoides*

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미기록 가거꼬리고사리(꼬리고사리과)의 계통학적 위치

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일본, 중국의 남서지방과 히말라야에 분포하는 *Asplenium yoshinagae* Makino (가거꼬리고사리: 신칭)가 전남 신안군 흑산면 가거도에서 발견되었다. 이 분류군은 무성아를 가지며 우편에 귀가 발달하는 점에서 꼬리고사리속 내에서 차꼬리고사리, 개차꼬리고사리, 깃고사리, 반들깃고사리, 개차고사리와 유사하나, 잎자루와 우편자루가 뚜렷이 발달하는 점, 우편의 끝이 뾰족한 점, 포막의 길이와 포자낭군의 모양이 다른 점들로 상기 종들과 구별된다. 가거꼬리고사리의 분류학적 위치를 파악하기 위하여 꼬리고사리속 22분류군과 군외군으로 버들참빗속 2분류군을 포함하여 24분류군을 대상으로 20개의 형태형질에 의한 maximum parsimony tree와 neighbor-joining tree를 작성하였다. 분석결과 꼬리고사리속은 군외군과 강하게 분리되었으며, 4개의 군으로 나누어 졌다. 가거꼬리고사리는 3번째군에 속하였으며, 2번째 군에 속하는 *A. hondoense* N. Murtakami & S. I. Hatanaka는 *Hymenasplenium*으로 다른 적이 있으나 본 형태 분석결과 *Asplenium*속에 속하였고, *Asplenium ruprechtii* 도 *Comptosorus*속으로 다루기 보다는 *Asplenium*속에 속하였다. 아울러 가거꼬리고사리의 형태적 특징을 기재하였고, 도해와 생태 사진을 첨부하였다.

주요어: 가거꼬리고사리, 꼬리고사리속, 미기록, 형태분류학적 위치

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