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The rust fungus *Gymnosporangium* in Korea including two new species, *G. monticola* and *G. unicorne*

Hye Young Yun[1]
Department of Forest Sciences, College of Agriculture and Life Sciences, Seoul National University, 56-1 Shillim-dong, Kwanak-gu, Seoul 151-921, Republic of Korea

Soon Gyu Hong[2]
Biological Resource Center, Korea Institute of Bioscience and Biotechnology, 52 Oun-dong, Yusong-ku, Daejeon 305-806, Republic of Korea

Amy Y. Rossman
Systematic Mycology and Microbiology Laboratory, Agricultural Research Service, United States Department of Agriculture, Beltsville, Maryland 20705

Seung Kyu Lee
Southern Forest Research Center, Korea Forest Research Institute, 719-1 Gazwa-dong, Jinju City Kyungsangnam-Do, 660-300, Republic of Korea

Kyung Joon Lee
Department of Forest Sciences, College of Agriculture and Life Sciences, Seoul National University, 56-1 Shillim-dong, Kwanak-gu, Seoul 151-921, Republic of Korea

Kyung Sook Bae[3]
Biological Resource Center, Korea Research Institute of Bioscience and Biotechnology, 52 Oun-dong, Yusong-ku, Daejeon 305-806, Republic of Korea

Abstract: A survey was conducted of the rust fungus *Gymnosporangium* in Korea. We recollected previously known species, namely *Gymnosporangium asiaticum*, *G. clavariiforme*, *G. globosum*, *G. japonicum* and *G. yamadae*. *Gymnosporangium nidus-avis* and *G. sabinae* are reported for the first time from Korea, and two new species, *G. monticola* sp. nov. and *G. unicorne* sp. nov., are recognized. Previous single reports of *G. miyabei* and *G. shiraianum* could not be confirmed. The LSU rDNA was sequenced from freshly collected specimens. Phylogenetic analyses show that species of *Gymnosporangium* form a monophyletic group with strong bootstrap support within the rust fungi. The two new species are unique based on both A and B molecular as well as morphological characteristics. Analyses of phenotypic characters mapped onto the phylogenetic tree show that teliospore length followed by telia shape and telia length are conserved; these are morphological characters useful in differentiating species of *Gymnosporangium*. Each of the nine species of *Gymnosporangium* in Korea is described and illustrated, and keys based on aecia and telia stages are provided. Lectotype specimens for several names described in *Gymnosporangium* are designated.

Key words: aecia stage, forest pathogens, LSU rDNA, Pucciniales, systematics, telia stage

INTRODUCTION

The rust fungi (Pucciniales) are important plant pathogens affecting a variety of angiosperms and gymnosperms, potentially causing severe damage to agricultural crops and forest trees (Scott and Chakravorty 1982, Swann et al 2001). Most rust fungi are specialized parasites that attack only certain genera or species of host plants. Species of *Gymnosporangium* are heteroecious, producing the aecia stage on leaves and fruits of pomaceous hosts (Rosaceae) and the telia stage on needles, green stems and branches of cedar (*Cupressus*) and juniper (*Juniperus*) (Cupressaceae; Kern 1973, Sinclair and Lyon 2005). Common diseases caused by *Gymnosporangium* include cedar apple rust (*G. juniperi-virginianae* Schwein.), European pear rust (*G. sabinae* [Dicks.] G. Winter) and Japanese pear rust (*G. asiaticum* Miyabe ex G. Yamada). *Gymnosporangium* is distributed mainly in the northern hemisphere with about 60 species of *Gymnosporangium* and 15 species of *Roestelia*, the aecia anamorph of *Gymnosporangium* (Hiratsuka 1936a–f, 1942; Parmelee 1965, 1971; Hiratsuka 1971; Kern 1973; Hiratsuka and Hiratsuka 1980; Peterson 1982; Sato and Sato 1982; Wang and Lin 1985; Lohsomboon et al 1990; Hiratsuka et al 1992; Lee and Kakishima 1999a, b; Lee et al 1999c).

In Korea diseases caused by *Gymnosporangium* are increasingly damaging because previously separated alternate hosts are being planted close to each other as landscape trees (Kim and Kim 1980). A number of species attack economically important plants such as apples. Species of *Gymnosporangium*, especially *G. yamadae*, are known to delay harvest of fruits by inhibiting photosynthesis and increasing respiration rate (Kim and Kim 1980). Some species of *Gymnosporangium* that attack economically important crops

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[1] Current address: Systematic Mycology and Microbiology Laboratory, Agricultural Research Service, United States Department of Agriculture, Beltsville, MD 20705.

[2] Current address: Polar BioCenter, Korea Polar Research Institute, KORDI, 7-50 Songdo-dong, Yeonsu-gu, Incheon 406-840, Republic of Korea.

[3] Corresponding author. E-mail: ksbae@kribb.re.k

are not widely distributed; thus they are considered to be of importance in the quarantine of plants (Smith et al 1992).

Relatively little molecular sequence data exist for rust fungi worldwide, and essentially nothing exists for species of *Gymnosporangium* from Asia. In one study analyzing the nuclear large subunit (LSU) or 28S rDNA sequences of 52 rust fungi, the three species of *Gymnosporangium*, *G. clavariiforme*, *G. cornutum* and *G. fuscum*, now regarded as *G. sabinae*, formed a monophyletic group (Maier et al 2003). In another study with 18S and 28S rDNA sequences (Aime 2006) two species of *Gymnosporangium*, *G. clavipes* and *G. juniperi-virginianae*, formed a unique lineage in the Pucciniales distinct from the Pucciniaceae.

This paper reports the results of a survey for *Gymnosporangium* in Korea, including a key, descriptions and illustrations for the nine species encountered. Two new species are described that are unique in both morphological and molecular characteristics. A phylogeny of the species from Korea is presented based on LSU rDNA sequence data and morphological characteristics evaluated based on this phylogeny.

MATERIALS AND METHODS

Sampling and morphological examination and identification.—One hundred thirteen telia and 78 aecia specimens of *Gymnosporangium* collected by the first author in Korea 2001–2006 were identified according to Parmelee (1965, 1971), Kern (1973), Wang and Lin (1985), Hiratsuka et al (1992) and Lee and Kakishima (1999a, b). The specimens are deposited at the Herbarium of Korea Forest Research Institute, Seoul, Korea (HKFRI). Also many specimens outside Korea were examined from the National Mycological Herbarium, Agriculture and Agri-Food Canada, Ontario (DAOM), Canada; Mycological Herbarium, Institute of Microbiology, Academia Sinica, China (HMAS); Hokkaido University Museum, Sapporo, Hokkaido, Japan (SAPA); Herbarium of Forest Mycology and Pathology, Forest and Forest Products Research Institute, Ibaraki, Japan (TFM); and U.S. National Fungus Collections, Beltsville, Maryland (BPI), abbreviated according to *Index Herbariorum*.

Identifications were made based on the host plant as well as morphological characteristics of the peridia, telia and teliospores. Each species is described with the specimens examined listed. Terminology for shapes and ornamentation of aecia and telia follows Kern (1973) and Cummins and Hiratsuka (1983). Names of colors are based on Kornerup and Wanscher (1978). Terminology for telia shapes follows the definitions in Kern (1973). The stages of the rust life cycle are indicated as follows: O, spermogonia; I, aecia; II, uredinia; and III, telia. Scientific names of host plants are based on Krussmann (1985), Chang (1994) and Lee (1999).

Specimens were rehydrated in distilled water 10–15 min at room temperature. Light microscopy was used to determine morphological characteristics, such as shape and size of peridium and peridial cells, shape, size and color of aeciospores and thickness of cell walls of aeciospores and teliospores. Spores were measured from specimens rehydrated and mounted in distilled water with a compound light microscope (Axiophot, Zeiss, Germany) at 400×. In general 30 spores were measured for each specimen (Parmasto and Parmasto 1987). Damaged, immature and irregular teliospores and peridial cells were not measured.

Evaluation of telia morphological characters.—Host relationships and morphological characters were numerically coded. Seven macroscopic and microscopic characters were analyzed. Characters with their character states are provided and numerically coded (TABLE III). The evolution of each phenotypic character was reconstructed onto the consensus tree of most parsimonious trees based on LSU rDNA sequences of the Korean species of *Gymnosporangium*. Fit of each character to the tree was evaluated by a consistency index (c) calculated with an algorithm in PAUP 4.0. Consistency index was defined as $c = m/s$, where m represents minimum amount of change that the character may show on any conceivable tree and s represents number of steps required by the character on the tree being evaluated (Swofford 1993).

DNA extraction, PCR and sequencing.—Total DNA was isolated from mature telia by protocols modified from those of Lecellier and Silar (1994). Dried and crushed telia were suspended in 500 μL lysis buffer (50 mM Tris-HCl [pH 8.0], 50 mM EDTA, 3% SDS). Telia suspensions were frozen in liquid nitrogen 1 min, incubated at 70 C for 2 min and vortexed at high speed 1 min. This process was repeated three times. RNA was removed by 0.5 μL RNase A (20 mg/mL) treatment at 37 C for 30 min. DNA was purified by phenol, phenol:chloroform and chloroform extractions. Purified DNA was precipitated with 1 volume isopropanol and collected by centrifugation at 12 000 rpm 10 min at room temperature. The pellet was washed with 70% ethanol, air-dried, and suspended in 50 μL sterile distilled water.

The D1/D2 domain of the 28S rDNA was amplified with the primer pair, forward primer No. 4 (5′-ACCCGCTGAAYTTAAGCATAT-3′) and reverse primer No. 11 (5′-CTCCTTGGTCCGTGTTTCAAGACGG-3′) (van der Auwera et al 1994). PCR proceeded as follows: initial denaturation at 94 C for 3 min; 30 cycles, each consisting of denaturation at 94 C for 30 s, annealing at 55 C for 30 s, extension at 72 C for 1 min; final extension at 72 C for 10 min. PCR products were purified with Wizard PCR prep kit (Promega, Madison, Wisconsin) following the manufacturer's instructions. Nucleotide sequences were determined with BigDye terminator cycle sequencing kits (Applied Biosystems, Foster City, California) with the same primers as used in PCR amplification. Sequences were proofread, edited and merged into composite sequences with the jPHYDIT program (Jeon et al 2005).

GenBank numbers for sequences of recently collected specimens of *Gymnosporangium* from Korea are listed (TABLE I). Additional sequences included in the analyses were obtained from GenBank, specifically *G. clavariiforme* (AR426211), *G. clavipes* (DQ354545), *G. cornutum* (AF426210), *G. juniperi-virginianae* (AF522167, AY629316

TABLE I. Specimens of *Gymnosporangium* species used in this study

Species name	Specimen No.	Telia host	Sampling date	Location	28S rDNA GenBank accession number
G. asiaticum	HKFRI 1974	*Juniperus chinensis* L. cv. *kaizuka*	Mar 2002	KOREA. GYEONGGI: Suwon	FJ848741
G. asiaticum	HKFRI 1975	*Juniperus chinensis* L. var. *sargentii* Henry	Apr 2001	KOREA. GYEONGGI: Pocheon-gun	FJ848742
G. asiaticum	HKFRI 1976	*Juniperus chinensis* L. cv. *kaizuka*	Apr 2002	KOREA. SEOUL: Yeongdeungpo-gu	FJ848743
G. asiaticum	HKFRI 1977	*Juniperus chinensis* L. cv. *kaizuka*	Apr 2001	KOREA. GYEONGGI: Pocheon-gun	FJ848744
G. asiaticum	HKFRI 1978	*Juniperus chinensis* L. cv. *kaizuka*	Apr 2001	KOREA. GYEONGGI: Pocheon-gun	FJ848745
G. asiaticum	HKFRI 1979	*Juniperus chinensis* L. cv. *kaizuka*	Apr 2001	KOREA. JEJU: Jeju-si	FJ848746
G. asiaticum	HKFRI 1980	*Juniperus chinensis* L. cv. *kaizuka*	Apr 2002	KOREA. SEOUL: Yeongdeungpo-gu	FJ848747
G. asiaticum	HKFRI 1981	*Juniperus chinensis* L.	Apr 2002	KOREA. GYEONGBUK: Gyeongju	FJ848748
G. asiaticum	HKFRI 1982	*Juniperus chinensis* var. *sargentii* Henry	Apr 2002	KOREA. SEOUL: Yeongdeungpo-gu	FJ848749
G. asiaticum	HKFRI 2073	*Juniperus chinensis* L.	Apr 2002	KOREA. GANGWON: Wonju Gangwon-do	EF990780
G. asiaticum	HKFRI 2074	*Juniperus chinensis* L. cv. *kaizuka*	Mar 2001	KOREA. GYEONGGI: Pocheon-gun	FJ848750
G. cornutum	HKFRI 2105	*Juniperus rigida* Siebold & Zucc.	Mar 2001	JAPAN. HONSHU	FJ848766
G. japonicum	HKFRI 1987	*Juniperus chinensis* L.	Apr 2002	KOREA. JEJU: Jeju-si	FJ848751
G. japonicum	HKFRI 1988	*Juniperus chinensis* L.	Apr 2002	KOREA. JEJU: Jeju-si	FJ848752
G. japonicum	HKFRI 1989	*Juniperus chinensis* L.	Mar 2002	KOREA. GYEONGGI: Suwon	FJ848753
G. japonicum	HKFRI 1990	*Juniperus chinensis* var. *sargentii* Henry	Apr 2002	KOREA. JEJU: Jeju-si	FJ848754
G. japonicum	HKFRI 1991	*Juniperus chinensis* var. *sargentii* Henry	Apr 2002	KOREA. GYEONGBUK: Gyeongju	FJ559374
G. japonicum	HKFRI 1992	*Juniperus chinensis* L.	Apr 2001	KOREA. GYEONGGI: Suwon	FJ848755
G. japonicum	HKFRI 1993	*Juniperus chinensis* var. *horizontalis* Nakai	Apr 2001	KOREA. JEJU: Jeju-si	FJ848756
G. japonicum	HKFRI 1994	*Juniperus chinensis* var. *sargentii* Henry	Apr 2002	KOREA. JEJU: Jeju-si	FJ848757
G. japonicum	HKFRI 1995	*Juniperus chinensis* var. *horizontalis* Nakai	Apr 2002	KOREA. JEJU: Jeju-si	FJ848758
G. japonicum	HKFRI 1997	*Juniperus chinensis* var. *globosa* Hornibr.	Apr 2002	KOREA. JEJU: Jeju-si	FJ848759
G. monticola	HKFRI 1984	*Juniperus rigida* Siebold & Zucc.	May 2002	KOREA. SEOUL: Gwanak-gu	FJ848770
G. monticola	HKFRI 1985	*Juniperus rigida* Siebold & Zucc.	May 2001	KOREA. SEOUL: Gwanak-gu	FJ848771
G. unicorne	HKFRI 1971	*Juniperus chinensis* var. *globosa* Hornibr.	Apr 2002	KOREA. SEOUL: Dongdaemun-gu	FJ848767
G. unicorne	HKFRI 1972	*Juniperus chinensis* var. *globosa* Hornibr.	Apr 2001	KOREA. SEOUL: Dongdaemun-gu	FJ848768
G. unicorne	HKFRI 1973	*Juniperus chinensis* var. *sargentii* Henry	Apr 2002	KOREA. CHUNGNAM: Cheonan	FJ848769
G. yamadae	HKFRI 1969	*Juniperus chinensis* L.	Apr 2002	KOREA. GANGWON: Wonju	FJ848760

TABLE I. Continued

Species name	Specimen No.	Telia host	Sampling date	Location	28S rDNA GenBank accession number
G. yamadae	HKFRI 1998	*Juniperus chinensis* L.	Apr 2002	KOREA. GYEONGGI: Suwon	FJ848761
G. yamadae	HKFRI 1999	*Juniperus chinensis* L.	May 2002	KOREA. GYEONGGI: Pocheon-gun	FJ848762
G. yamadae	HKFRI 2000	*Juniperus chinensis* L.	May 2001	KOREA. GYEONGGI: Pocheon-gun	FJ559375
G. yamadae	HKFRI 2001	*Juniperus chinensis* L.	Apr 2002	KOREA. SEOUL: Yeongdeungpo-gu	FJ559373
G. yamadae	HKFRI 2002	*Juniperus chinensis* L. cv. *kaizuka*	Apr 2001	KOREA. SEOUL: Yeongdeungpo-gu	FJ848763
G. yamadae	HKFRI 2006	*Juniperus chinensis* L. cv. *kaizuka*	Apr 2002	KOREA. GYEONGGI: Bucheon	FJ848764
G. yamadae	HKFRI 2007	*Juniperus chinensis* L. cv. *kaizuka*	Apr 2001	KOREA. GYEONGGI: Bucheon	FJ848765

and DQ354547), *G. libocedri* (AF522168), *G. sabinae* (AF426209, AY512845) as cited in Maier et al (2003), Aime (2006) and Aime et al (2006). *Coleosporium asterum* (AF522164), *Puccinia coronata* f. sp. *avenae* (AY114290), *Puccinia graminis* (AF522177) and *Uromyces appendiculatus* (AF522182), also from the GenBank database, were used as outgroup taxa based on rust phylogenies (Maier et al 2003, Aime 2006, Aime et al 2006). The alignment has been deposited as TreeBase SN4406.

Phylogenetic analysis.—The 35 sequences obtained in this study and 13 sequences retrieved from GenBank were aligned by pairwise alignment function and manually adjusted with secondary structural model of eukaryotic LSU rRNA (de Rijk et al 1998) with jPHYDIT. The most parsimonious tree was obtained by heuristic search with TBR branch swapping on starting trees generated with 100 random addition sequences using PAUP 4.0 10b (Swofford 2002). Search settings were steepest descent option not in effect, zero length branches were set to collapse to yield polytomies and MULTREES option was in effect. Bootstrap values were evaluated by 1000 replications using a heuristic search with simple addition sequences, TBR branch swapping and MULTREES in effect. A maximum likelihood tree was obtained by heuristic search option using TBR branch swapping with the TVM + I + G model, which was deduced as the best fit for the data by AIC test with MODELTEST 3.7 (Posada and Crandall 1998). Search settings were the same as parsimony tree reconstruction, except that MULTREES was turned off. Bootstrap values were evaluated by 1000 replications with the fast heuristic algorithm. A neighbor joining tree was reconstructed based on the distance matrix calculated with Kimura's two-parameter model (Kimura 1980). Bootstrap values were evaluated by 1000 replications with the same methods. Bootstrap values for maximum parsimony (MP), maximum likelihood (ML) and neighbor joining (NJ) analyses are shown at the nodes.

RESULTS

Survey.—Rust fungus analysis yielded specimens of *Gymnosporangium* from every province of Korea (FIG. 1 and listed below in specimens cited). We recollected five species, namely *Gymnosporangium asiaticum*, *G. clavariiforme*, *G. globosum*, *G. japonicum* and *G. yamadae*. Several new aecia hosts for these species are reported: *G. asiaticum* on *Pyrus ussuriensis*

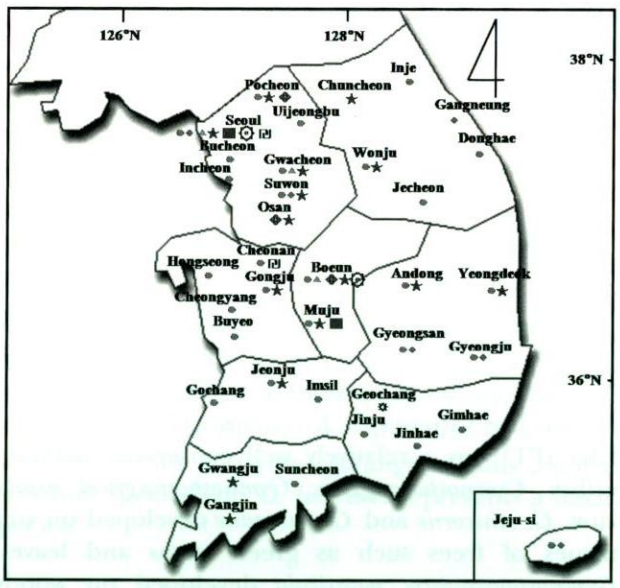

FIG. 1. Geographical distribution of species of *Gymnosporangium* in Korea. Symbols represent the locality where each species was collected. (●) *G. asiaticum*, (■) *G. clavariiforme*, (❖) *G. globosum*, (□) *G. japonicum*, (▲) *G. monticola*, (۞) *G. nidus-avis*, (☼) *G. sabinae*, (卍) *G. unicorne*, (★) *G. yamadae*.

var. *seoulensis*, *G. clavariiforme* on *Crataegus pinnatifida* and *G. yamadae* on *Malus prunifolia*. *Gymnosporangium nidus-avis* and *G. sabinae* are reported herein for the first time from Asia. *Gymnosporangium nidus-avis* was collected at two sampling sites on *Juniperus chinensis*, while *G. sabinae* was found only once also on *J. chinensis*. *Gymnosporangium globosum*, cause of American hawthorn rust, was reported for the first time from Asia on two new host plants, namely *Crataegus pinnatifida* and *C. pinnatifida* var. *major* (Yun et al 2008). Two new species, one of which was mistakenly reported as *G. cornutum* (Yun et al 2003), were discovered as described below. *G. juniperi* Link (Hiratsuka 1942), *G. miyabei* (Hiratsuka 1940) and *G. shiraianum* (Park 1958) were not found during extensive fieldwork or in any herbarium. The name *G. juniperi* Link is considered a nomen ambiguum (Kern 1973). The distribution of *Gymnosporangium miyabei* and *G. shiraianum* apparently is restricted to Japan (Farr et al 2008). The host range for the nine species of *Gymnosporangium* in Korea is listed (TABLE II). A key to species of *Gymnosporangium* from Korea is presented, and each species is described and illustrated below.

Evolution of telia host and morphological characters.—The phylogenetic tree of Korean species resulting from the molecular study was used to map telia host and morphological characters. Host and morphological characters as a numerical coding are mapped on the phylogenetic tree (FIG. 3). The consistency index for each character is provided (FIG. 4). Among the seven characters examined in this study, length of teliospores had the highest consistency index (1.0) (FIG. 4). Telia shape and length (0.7 and 0.4 respectively) had a relatively high consistency index as well.

In distinguishing species of *Gymnosporangium* in Korea, host relationships in the telia stage (TH) (TABLE II) are only moderately useful. *Gymnosporangium monticola* occurs only on *Juniperus rigida*, and conversely *J. rigida* was infected only by *G. monticola*. All other species of *Gymnosporangium* in Korea occur on the five varieties of *J. chinensis*. The position of telia (PT) was a relatively well conserved character within *Gymnosporangium*. *Gymnosporangium asiaticum*, *G. unicorne* and *G. yamadae* developed on soft tissues of trees such as green stems and leaves. *Gymnosporangium monticola* developed on woody stems and *G. japonicum* on hard tissues such as trunks and branches. The shape of telia (TS) is unique for two species. *Gymnosporangium asiaticum* exhibits two different types of telia, namely (i) aggregated, bluntly conical and (ii) aggregated, conical, on witches' broom. The telia of *G. unicorne* are always solitary but may be either hemispherical or sharply conical. *Gymnosporangium yamadae* has two different types of telia, small gall having cylindrical-acuminate sori and big gall with tongue-shaped sori. *Gymnosporangium japonicum* has wedge-shaped telia, while those of *G. monticola* are fusiform with applanate sori. The length of the telia (TL) is a well conserved character in *G. asiaticum*, *G. japonicum*, *G. monticola* and *G. unicorne* but highly variable in *G. yamadae*. *Gymnosporangium asiaticum*, *G. monticola* and *G. unicorne* have small (<3 mm) telia, and *G. japonicum* have medium (3–6 mm) telia. *Gymnosporangium yamadae* telia are variable in length (1–9 mm). The presence or absence of an apical pore in the teliospores was one of the least useful characters included in this analysis. *Gymnosporangium japonicum* shows consistency within the species in lacking an apical pore, and *G. monticola* and *G. unicorne* have apical pores in all specimens. The other two species, *G. asiaticum* and *G. yamadae*, have teliospores with or without apical pores. The teliospore wall color (TSC) is variable in *G. asiaticum*, *G. japonicum* and *G. yamadae*, which are generally pale orange to orange, although one specimen of *G. japonicum* has light brown teliospores. *G. monticola* has consistently orange teliospores. Length of teliospores (TSL) is a well conserved character. *Gymnosporangium asiaticum*, *G. unicorne* and *G. yamadae* have small teliospores (<48 μm), *G. japonicum* has large teliospores (>48 μm), while *G. monticola* teliospores are 37–60 μm.

Analysis of LSU rDNA.—Among the 745 aligned bp, 597 were constant, 62 were variable but parsimony uninformative and 86 were parsimony informative. Parsimony analysis resulted in 84 equally parsimonious trees with 249 steps (one of which is shown in FIG. 2). Differences among equally parsimonious trees were confined to relationships within species. Consistency and retention indices were respectively 0.711 and 0.883. The phylogenetic analysis of *Gymnosporangium* reveals that eight species, *G. asiaticum*, *G. cornutum*, *G. japonicum*, *G. juniperi-virginianae*, *G. monticola*, *G. sabinae* (representing the type species, *G. fuscum*), *G. unicorne* and *G. yamadae*, form a well supported group with *G. libocedri* basal to the other species of *Gymnosporangium*. The 11 specimens of *G. asiaticum* formed a monophyletic group with 79% bootstrap support. Three specimens of *G. unicorne* grouped with 91% bootstrap value and were distinct from *G. asiaticum* with 6 or 8 bp sequence differences. The relationship of *G. asiaticum* with *G. unicorne* was supported by 98% bootstrap value. The sequences of *G. cornutum* (Germany, Japan) from GenBank showed a close

relationship but were distinct from the similar looking species from Korea that herein is described as a new species, *G. monticola*. The two specimens of *G. monticola* in Korea formed a monophyletic group with strong bootstrap support (96%). Ten specimens of *G. japonicum* consisting of two genotypes and eight specimens of *G. yamadae*, all of the same genotype, formed a monophyletic group, both with strong bootstrap support (100%). Bootstrap values from the maximum likelihood analyses showed strong support for each species: 100% for *G. japonicum*, 94% for *G. monticola*, 88% for *G. unicorne* and 94% for *G. yamadae*.

DISCUSSION

Among the nine species of *Gymnosporangium* in Korea, three, specifically *G. asiaticum*, *G. japonicum* and *G. yamadae*, are common and widespread throughout Korea as well as the rest of Asia. *Gymnosporangium asiaticum* is considered a potential threat in the United States because of the damage this species can cause to pears and other rosaceous plants (Cline and Farr 2006). For many decades this species has been found in the United States on imported nursery stock, often of *Juniperus chinensis* and *Pyrus pyrifolia*, both Asian plants, and once in Europe (Blasdale 1919; Hotson 1925; Hunt 1926; Greene 1968; Shaw 1973; French 1987, 1989; Henderson 2000). However no evidence suggests that *G. asiaticum* has been established outside Asia. *Gymnosporangium japonicum* also is reported occasionally from USA, in most cases on *Juniperus chinensis* stock (BPI 854937 and BPI 854938) imported from Japan in Connecticut. *Gymnosporangium yamadae* has been reported on landscape trees, *Malus toringo*, in USA (Yun et al 2009). This rust can attack cultivated apple (*Malus domestica*) (Anonymous 1995).

Four species of *Gymnosporangium* are found only rarely in Korea but are widespread elsewhere. *Gymnosporangium clavariiforme* is common in North America and Europe (Laundon 1977a); however it has been reported rarely in Asia, specifically China (Tai 1979), Japan (Kobayashi 2007) and Korea (Spaulding 1961). This species was found only in two locations in Korea with aecia and telia stages occurring on native Asian hosts. Similarly *Gymnosporangium globosum*, cause of American hawthorn rust known primarily in North America (Kern 1973, Farr et al 2008), was discovered in Korea on the native Asian hosts *Crataegus pinnatifida* and *C. pinnatifida* var. *major* (Yun et al 2008). Not known elsewhere in Asia, this rust species poses a threat to rosaceous hosts. The telia state of *G. globosum* on *Juniperus* has not been discovered in Asia. *Gymnosporangium nidus-avis* was collected at two sites on *J. chinensis* and represents a new record for Korea. Widespread in temperate North America, the most common aecia host is *Amelanchier* spp. (serviceberry) and thus is not as potentially damaging in Korea as other species of *Gymnosporangium*. Another new record for Korea, *Gymnosporangium sabinae*, was found only once on *Juniperus chinensis*. This species causes European pear rust and is widespread in Europe, rarely reported in North America and recently recorded in northwestern China (Zhuang 2005).

The two newly described species in Korea, *G. monticola* and *G. unicorne*, might have been mistakenly identified as other known species. Specimens described as the new species *G. monticola* were reported from Korea as *G. cornutum* (Yun et al 2003), a rust species widespread in northern temperate regions (Kern 1973, Farr et al 2008). *Gymnosporangium monticola* is phylogenetically distinct from *G. cornutum*, and the morphological differences between these species are discussed below (TAXONOMY). Aecia and telia stages of *G. monticola* were found on native host plants in Korea. *G. unicorne* is morphologically similar to *G. asiaticum*, and these species might have been confused in the past.

Several characters, especially teliospore length and telia shape, are useful in discriminating among species of *Gymnosporangium*. Teliospore length is a character traditionally used to define rust taxa (Kern 1973), and the consistency index of 1.0 confirms its usefulness. Telia shape is also an important character that has been used in defining species (Kern 1973). Telia shape is variable for *G. asiaticum*, *G. unicorne* and *G. yamadae*; however the variability within each species is unique. Another traditionally used character, telia host, was only moderately useful in distinguishing species of *Gymnosporangium* in Korea, probably because so many species occur on varieties of *Juniperus chinensis*.

The results of our phylogenetic analysis of *Gymnosporangium* for eight species of *Gymnosporangium* are similar to those of Aime (2006) and Maier et al (2003), who respectively include two and three species. All studies show that *G. sabinae*, the type species of *Gymnosporangium*, falls among the other species and *G. libocedri* represents a basal species.

TAXONOMY

A key to the nine species of *Gymnosporangium* from Korea is provided below. This is followed by a brief description of each species based primarily on specimens from Korea, although some reference specimens also have been examined. Hosts from

TABLE II. Host range of *Gymnosporangium* reported in Korea

Species name	Host plants species	References
	Cupressaceae	
G. asiaticum	*Juniperus chinensis* L.	[a]Hiratsuka (1935), [b]Yun et al (2005)
	J. chinensis L. var. *sargentii* Henry	[a]Korean Soc. Plant Prot. (1986)
	J. chinensis cv. *kaizuka*	[b]Yun et al (2005)
G. clavariiforme	*Juniperus rigida* Siebold & Zucc.	[a]Hiratsuka (1935), [a]Present study
G. japonicum	*Juniperus chinensis* L.	[b]Yun et al (2003, 2005)
	J. chinensis L. var. *horizontalis* Nakai	[b]Yun et al (2003, 2005)
	J. chinensis L. var. *sargentii* A. Henry	[a]Yun et al (2003)
	J. chinensis L. var. *globosa* Hornibr.	[a]Yun et al (2003)
G. monticola	*Juniperus rigida* Siebold & Zucc.	[b]Yun et al (2005 as *G. cornutum*)
G. unicorne	*Juniperus chinensis* L. var. *globosa* Hornibr.	[b]Yun et al (2005 as *G. asiaticum*)
	J. chinensis L. var. *sargentii* A. Henry	[b]Yun et al (2005 as *G. asiaticum*)
G. yamadae	*Juniperus chinensis* L.	[a]Hiratsuka (1935)
	J. chinensis L. cv. *kaizuka*	[b]Yun et al (2005)
	Rosaceae	
G. asiaticum	*Chaenomeles japonica* (Thunb.) Lindl. ex Spach	[a]Kim (1963)
	C. speciosa (Sweet) Nakai	[a]Park (1961), [b]Yun et al (2005)
	Malus toringo (Siebold) Siebold ex de Vriese	[a]Park (1961)
	Pseudocydonia sinensis (Thouin) C. K. Schneid.	[a]Park (1961), [b]Lee and Lim (1984), [b]Yun et al (2005)
	Pourthiaea villosa (Thunb.) Decne. var. *laevis* (Thunb.) Stapf	[a]Hiratsuka (1942)
	Photinia villosa var. *brunnea* Nakai	[a]Park (1958), [a]Present study
	Pyrus communis L.	[a]Kim (1963)
	P. fauriei C. K. Schneid.	[a]Hiratsuka (1942)
	P. pyrifolia (Burm. f.) Nakai	[a]Chung et al (1977)
	P. pyrifolia (Burm. f.) Nakai var. *culta* (Makino) Nakai	[a]Park (1958), [b]Lee and Lim (1984), [b]Yun et al (2005)
	P. seoulensis Nakai	[a]Hiratsuka (1942)
	P. sinensis Lindl. var. *culta* MAK.(Nashi)	[a]Hiratsuka N. (1935)
	P. ussuriensis Maxim.	[a]Hiratsuka (1942), [b]Yun et al (2005)
	P. ussuriensis var. *seoulensis* T. Lee	[a]Present study
G. clavariiforme	*Crataegus pinnatifida* Bunge	[a]Present study
	C. pinnatifida Bunge var. *psilosa* C. K. Schneid.	[a]Chung et al (1977)
	Sorbus alnifolia (Siebold & Zucc.) K. Koch	[a]Hiratsuka (1940)
G. globosum	*Crataegus pinnatifida* Bunge	[a]Yun et al (2008)
	C. pinnatifida Bunge var. *major* N. E. Br.	[a]Yun et al (2008)
G. japonicum	*Photinia villosa* (Thunb.) DC.	[b]Yun et al (2003)
	P. villosa var. *brunnea* Nakai	[b]Yun et al (2003)
G. juniperi	*Pyrus pyrifolia* var. *culta* Nakai	[a]Korean Soc Plant Prot (1986)
	Sorbus sp.	[a]Hiratsuka (1942)
G. miyabei	*Sorbus alnifolia* (Siebold & Zucc.) K. Koch	[a]Hiratsuka (1940)
G. monticola	*Sorbus alnifolia* (Siebold & Zucc.) K. Koch	[b]Yun et al (2005 as *G. cornutum*)
G. shiraianum	Not described	[a]Park (1958)
G. unicorne	*Crataegus pinnatifida* Bunge	[b]Yun et al (2005 as *G. asiaticum*)
	Chaenomeles speciosa (Sweet) Nakai	[b]Yun et al (2005 as *G. asiaticum*)
	Pseudocydonia sinensis (Thouin) C. K. Schneid.	[b]Yun et al (2005 as *G. asiaticum*)
	Pyrus pyrifolia (Burm. f.) Nakai var. *culta* (Makino) Nakai	[b]Yun et al (2005 as *G. asiaticum*)
	P. ussuriensis Maxim.	[b]Yun et al (2005 as *G. asiaticum*)
G. yamadae	*Malus baccata* (L.) Borkh.	[a]Hiratsuka (1940), [a]Present study
	M. halliana Koehne	[a]Hiratsuka (1942)
	M. prunifolia (Willd.) Borkh.	[a]Present study
	M. pumila Mill.	[a]Takimoto (1916), [b]Lee and Lim (1984), [b]Yun et al (2005)
	M. pumila Miller var. *dulcissima* Koidzumi	[a]Takimoto (1916)
	M. mandshurica (Maxim.) Kom. ex Skvortsov	[a]Hiratsuka (1940)
	M. toringo (Siebold) Siebold ex de Vriese	[b]Yun et al (2005)

Host range studies were conducted by: [a] plant hosts confirmed by fungi collection growing under natural conditions; [b]plant hosts confirmed by artificial inoculation.

TABLE III. Characters with character states used in data matrix

A. Telia host (TH)
- 1: *Juniperus chinensis* L.
- 2: *Juniperus chinensis* L. cv. *kaizuka*
- 3: *Juniperus chinensis* L. var. *sargentii* Henry
- 4: *Juniperus chinensis* L. var. *horizontalis* Nakai
- 5: *Juniperus chinensis* L. var. *globosa* Hornibr.
- 6: *Juniperus rigida* Siebold & Zucc.

B. Position of telia (PT)
- 1: trunk; 2: branch; 3: woody stems; 4: green stems; 5: leaves

C. Telia shape (TS)
- 1: solitary, hemispherical
- 2: solitary, sharply conical
- 3: aggregated, bluntly conical
- 4: wedge
- 5: aggregated-conical on witches' broom
- 6: small galls (1–3 mm), sori cylindrical-acuminate
- 7: large galls (5–9 mm), sori tongue
- 8: fusiform, sori applanate

D. Telia length (TL)
- 1: <3 mm; 2: 3–6 mm; 3: >6 mm

E. Apical pore in teliospore (APT)
- 1: yes; 2: no

F. Teliospore color (TSC)
- 1: pale orange; 2: orange; 3: light brown

G. Teliospore length (TSL)
- 1: <48 μm; 2: >48 μm

Korea are listed and summarized (TABLE II). The worldwide distribution for each species is noted. General references on *Gymnosporangium*, such as Kern (1973), Hiratsuka et al (1992) and Farr et al (2008), should be consulted for a complete list of hosts for each species.

KEY TO SPECIES OF *GYMNOSPORANGIUM* IN KOREA BASED ON TELIA STATE, ALL ON *JUNIPERUS* (CUPRESSACEAE)

1. Telia on *Juniperus rigida* and its varieties, caulicolous 2
1. Telia on *Juniperus chinensis* and its varieties, foliicolous or caulicolous 3
   2(1). Telia solitary, applanate or pulvinate; teliospores dark brown, broadly ellipsoid, 36–63 × 16–29 μm. . . . . *G. monticola*
   2(1). Telia aggregated, long fusiform; teliospores pale orange, narrowly fusiform, 38–99 × 13–23 μm. . . . . *G. clavariiforme*
3(1). Telia on small or large galls; teliospores ellipsoid or obovoid, 31–56 × 15–28 μm . . . . . *G. yamadae*
3(1). Telia not on galls. 4
   4(3). Telia caulicolous 5
   4(3). Telia foliicolous or on young, green stems . . . 7
5(4). Telia developing on fusiform swellings or witches' broom of woody stems. 6
5(4). Telia not distorting woody stems or branches, irregularly wedge-shaped, 3–6 mm high × 2–3 mm wide; teliospores ellipsoid to long-ellipsoid, pale orange to orange, rarely light brown, 36–70 × 13–22 μm. . . . . *G. japonicum*
   6(5). Telia causing fusiform swelling, conical or tongue-shaped, 4–7 mm high; teliospores ellipsoid, brownish orange, 38–51 × 19–25 μm . . . . . *G. sabinae*
   6(5). Telia causing fusiform swelling or witches' broom, hemispherical, 2–5 mm high; teliospores ellipsoid or ovoid, pale brown, known as orange peel based on Kornerup & Wanscher (1978), 41–55 × 18–26 μm . . . . . *G. nidus-avis*
7(4). Telia developing on witches' broom, aggregated, variable in shape, bluntly conical, hemispherical, pulvinate, or somewhat wedge-shaped; teliospores broadly to narrowly ellipsoid, 31–54 × 15–27 μm . . . . . *G. asiaticum*
7(4). Telia not developing on witches' broom, solitary, hemispherical to sharply conical; teliospores fusiform, 31–47 × 15–23 μm . . . . . *G. unicorne*

KEY TO SPECIES OF *GYMNOSPORANGIUM* IN KOREA BASED ON AECIA STAGE, ALL ON ROSACEAE

Host: Aecia mostly on *Chaenomeles*, *Crataegus* and *Pyrus*. . . 1
1. Aecia splitting above and becoming lacerate. . . . 2
1. Aecia not splitting 3
   2(1). Aecia 3–7 mm high; peridial cells rhomboid, 39–103 μm long; aeciospores globose, large coronate, 17–25 × 15–22 μm . . . . . *G. asiaticum*
   2(1). Aecia 2–4 mm high; peridial cells linear-rhomboidal, 60–90 μm long; aeciospores globose or broadly ellipsoid, small coronate, 19–27 × 16–20 μm . . . . . *G. globosum*

Note: Distinguishing *G. asiaticum* from *G. globosum* based on the aecia stage is difficult and requires SEM observation of the surface of peridial cells and aeciospores.

3(1). Peridium cornute, narrowing at apex, 1–7.2 mm high; peridial cells rhomboid, 33–81 μm long; aeciospores irregularly globose, large coronate, 14.5–24 × 13–23.5 μm . . . . . *G. unicorne*
3(1). Peridium tubular, 0.5–1.8 mm high; peridial cells long, narrow, 83–125 μm; aeciospores globose, echinulate, 22–32 × 19–28 μm. . . . *G. clavariiforme*

Host: Aecia mostly on *Malus*, peridium elongated, cornuted, 2–5 mm high, peridial cells with long papillae, 63–102 μm long. . . . . *G. yamadae*

Host: Aecia mostly on *Photinia*, peridium tubular, peridial cells with short papillae, 62–117 μm long . . . . . *G. japonicum*

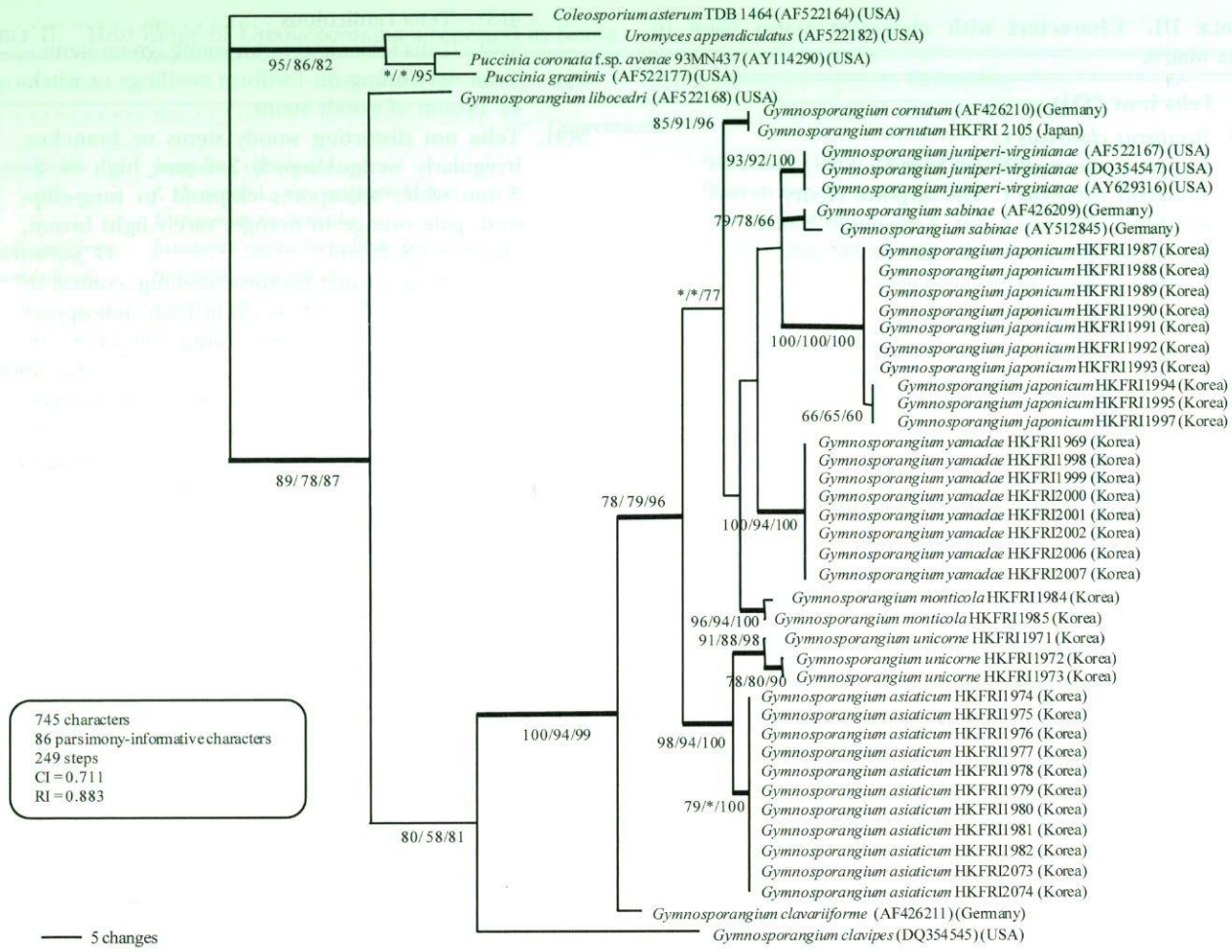

FIG. 2. One of the 84 equally parsimonious trees of 28S rDNA sequences. Thick lines represent branches conserved in all three analyses. Bootstrap values higher than 50 are indicated at branches as follows: MP/ML/NJ.

Host: Aecia mostly on *Sorbus*, peridium cornute, rupturing at apex, becoming lacerate, peridial cells with short papillae, 48–101 μm long. . . . . *G. monticola*

DIAGNOSES, NOTES AND SPECIMENS EXAMINED OF *GYMNOSPORANGIUM* IN KOREA

Gymnosporangium asiaticum Miyabe ex G. Yamada, Shokubutse Byorigaku (Pl. Path) Tokyo Hakubunkwan 37(9):304, 1904. FIG. 5

= *Gymnosporangium haraeanum* Syd. & P. Syd. 1912.
= *Gymnosporangium spiniferum* Syd. & P. Syd. 1912.
= *Gymnosporangium chinense* Long 1914.
= *Gymnosporangium koreaense* (Henn.) H.S. Jacks. 1916.

Aecia foliicolous and caulicolous, hypophyllous, 3–7 mm high; peridium tubular, lacerating at apex or spreading. Peridia cells rhomboid, 39–103 μm long, outer walls smooth, inner walls small papillate and side walls moderately rugose; aeciospores globose, large coronate, 17–25 × 13–22 μm, walls yellowish, 1.0–2.0 μm thick.

Telia foliicolous or on green stems, developing on witches' broom but without causing swelling on stem, aggregated bluntly conical, hemispherical, pulvinate or somewhat wedge-shaped; 2–4 mm high, brownish orange; teliospores 2-celled, broadly to narrowly ellipsoid, 31–54 × 15–27 μm (L:W = 2.3), walls 1.0–2.5 μm, pale orange to orange, pores 1 or 2 near septum or 1 apical in upper cell.

Disease. Japanese pear rust.

Hosts in Korea. O, I: *Chaenomeles speciosa* (Sweet) Nakai, *Pseudocydonia sinensis* (Thouin) C.K. Schneid., *Pyrus pyrifolia* (Burm. f.) Nakai var. *culta* (Makino) Nakai, *Pyrus ussuriensis* Maxim., *P. ussuriensis* var. *seoulensis* T. Lee. III: *Juniperus chinensis* L., *J. chinensis* cv. *kaizuka*

Distribution. Common in Asia (China, Japan, Hong Kong, Korea, Taiwan); reports from the USA and UK are based on imported nursery stock. This rust species has not become established outside its native range in Asia.

Specimens examined. CHINA. BEIJING: on *Pyrus betulaefolia*, 5 Jul 1930, *HMAS 08634*; 13 Jun 1958, *HMAS 25370*; on *Pseudocydonia sinensis*, 2 Jun 1933, *HMAS 14328*; on *Chaenomeles speciosa*, 13 May 1977, *HMAS 37073*; 22 May 1977, *HMAS 38642*; on *Pyrus ussuriensis*

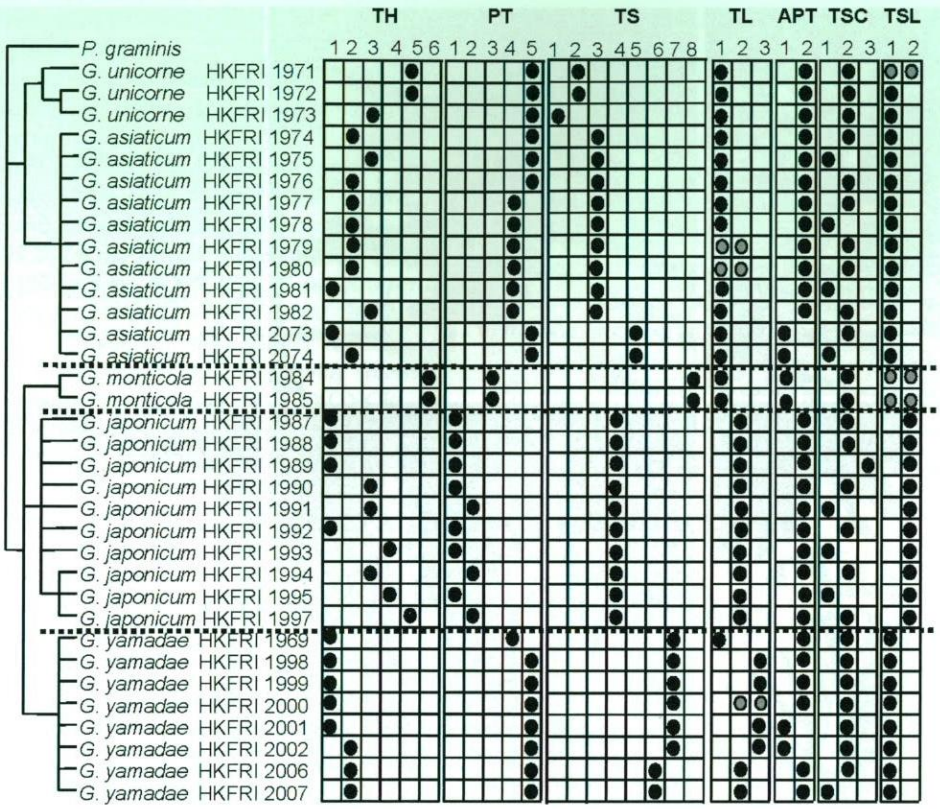

FIG. 3. Variation of host relationships and morphological characters on parsimony tree of 28S rDNA sequences. This is a strict consensus tree of three equally parsimonious trees. Abbreviations: TH, telia host; PT, position of telia; TS, telia shape; TL, telia length; APT, apical pore in teliospore; TSC, teliospore color; TSL, teliospore length. (Character states are listed and defined in TABLE III.)

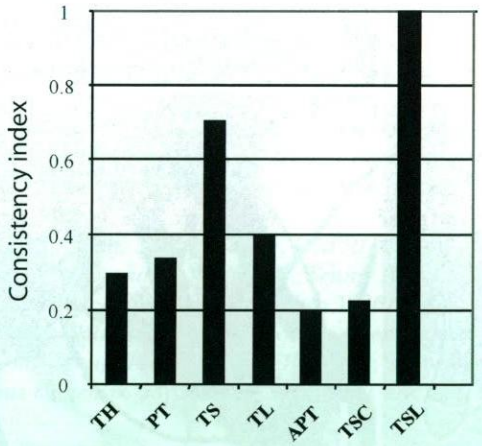

FIG. 4. Consistency index of host relationships and morphological characters based on the parsimony tree (FIG. 3). Abbreviations: TH, telia host; PT, position of telia; TS, telia shape; TL, telia length; APT, apical pore in teliospore; TSC, teliospore color; TSL, teliospore length. (Character states are listed and defined in TABLE III.)

var. *seoulensis*, 25 Apr 1951, *HMAS 22176*. on *Pyrus pyrifolia* var. *culta*, 7 Jul 1973, *HMAS 38645*; on *Pyrus pyrifolia* var. *culta*, 27 May 1980, *HMAS 41573*. JAPAN. on *Juniperus chinensis* var. *procumbens*, Apr 1979, *TFM 4948*. KOREA. CHUNGBUK: Boeun-gun, on *Pseudocydonia sinensis*, 15 Jul 1999, *Kyoung Hee Kim, HKFRI 751*; on *Pyrus ussuriensis*, 15 Jul 1999, *Kyoung Hee Kim, HKFRI 743*; Cheongju, on *Chaenomeles speciosa*, 14 Jul 1999, *Seung Kyu Lee, HKFRI 218*; Jecheon, on *Juniperus chinensis*, 14 Apr 2000, *Seung Kyu Lee, HKFRI 480*; 14 Apr 2000, *Kyoung Hee Kim, HKFRI 479*. CHUNGNAM: Buyeo-gun, on *Juniperus chinensis*, 1 May 2000, *Seung Kyu Lee, HKFRI 495*; on *Juniperus chinensis*, 1 May 2000, *Kyoung Hee Kim, HKFRI 495*; Cheonan, on *Chaenomeles speciosa*, 14 Jul 1999, *Kyoung Hee Kim, HKFRI 217*; on *Pseudocydonia sinensis*, 14 Jul 1999, *Kyoung Hee Kim, HKFRI 243, HKFRI 247*; Cheongyang-gun, on *Pseudocydonia sinensis*, 13 Jul 1999, *Kyoung Hee Kim, HKFRI 241*; Gongju, on *Pseudocydonia sinensis*, 12 Jul 1999, *Seung Kyu Lee, HKFRI 750*; on *Pseudocydonia sinensis*, 12 Jul 1999, *Seung Kyu Lee, HKFRI 240*; Hongseong-gun, on *Pyrus ussuriensis*, 13 Jul 1999, *Seung Kyu Lee, HKFRI 742*. CHUNGBUK: Muju-gun, on *Juniperus chinensis*, 30 Apr 1999, *Kyoung Hee Kim, HKFRI 2011*. GANGWON: Donghae, on *Pseudocydonia sinensis*, 12 Jul 2002, *Hye Young Yun, HKFRI 2948*; Inje-gun, on *Pyrus ussuriensis*, 22 Jul 1999, *Kyoung Hee Kim, HKFRI 746*. GYEONGGI: Bucheon, on *Chaenomeles speciosa*, 2 Aug,

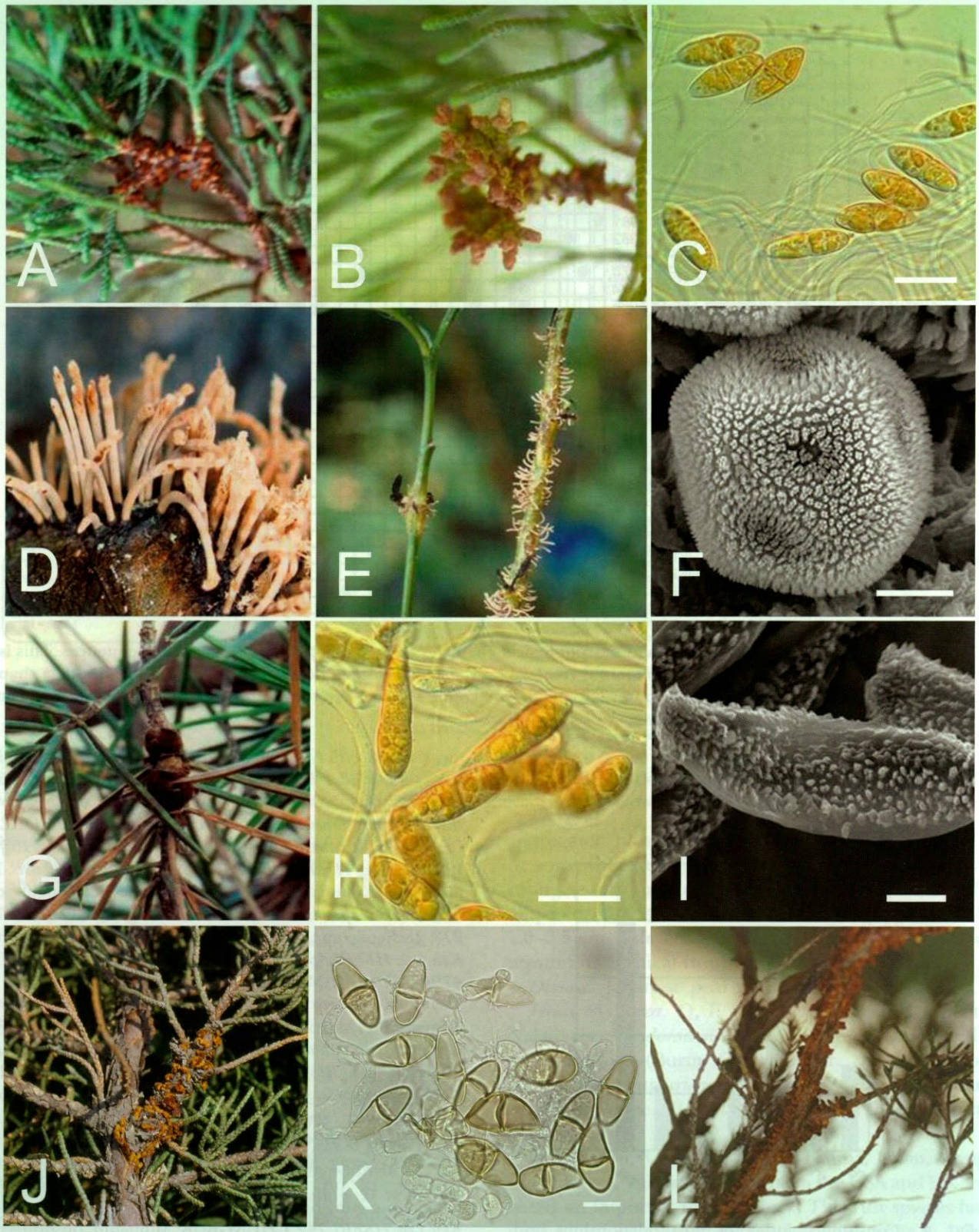

FIG. 5. Macroscopic and microscopic features of *Gymnosporangium asiaticum*, *G. clavariiforme* and *G. sabinae*. A–F. *Gymnosporangium asiaticum*. A. Telia (aggregated, bluntly conical) on *Juniperus chinensis* cv. *kaizuka* (HKFRI 1974). B. Telia (witches' broom) on *J. chinensis* cv. *kaizuka* (HKFRI 2074). C. Teliospores (HKFRI 1974). D. Aecia on *Pyrus pyrifolia* var. *culta* (HKFRI 2033). E. Aecia on *P. ussuriensis* (HKFRI 2036). F. Surface structures of aeciospores on *P. pyrifolia* var. *culta* (HKFRI

2001, *Hye Young Yun, HKFRI 2032*; on *Juniperus chinensis* cv. *kaizuka*, 24 Apr 2001, *Hye Young Yun, HKFRI 2013*; 13 Apr 2001, *Hye Young Yun, HKFRI 2008*; 20 Jul 2002, *Hye Young Yun, HKFRI 2029*; Gwacheon, on *Juniperus chinensis*, 15 Apr 2000, *Seung Kyu Lee, HKFRI 1781*; 19 Apr 2001, *Seung Kyu Lee, HKFRI 2010*; *HKFRI 2015*; Pocheon-gun, on *Juniperus chinensis*, 4 May 2000, *Kyoung Hee Kim, HKFRI 436*; on *Juniperus chinensis* cv. *kaizuka*, 28 Mar, 2001, *Hye Young Yun, HKFRI 2074*; Suwon, on *Chaenomeles speciosa*, 26 Jun 2001, *Hye Young Yun, HKFRI 2030*; on *Juniperus chinensis*, 10 Apr 2000, *Seung Kyu Lee, HKFRI 2017*; on *Juniperus chinensis* cv. *kaizuka*, 25 Mar 2002, *Hye Young Yun, HKFRI 1974*; Uijeongbu, on *Pseudocydonia sinensis*, 19 Jun 1998, *Seung Kyu Lee, HKFRI 755*. GYEONGBUK: Andong, on *Juniperus chinensis*, 14 Apr 2000, *HKFRI 458*; on *Pseudocydonia sinensis*, 25 Jun, 1999, *Seung Kyu Lee, HKFRI 236*; Gyeongsan, on *Juniperus chinensis*, 10 Apr 1998, *Seung Kyu Lee, HKFRI 1135*; Yeongdeok-gun, on *Juniperus chinensis*, 14 Apr 2000, *Seung Kyu Lee, HKFRI 481*. GYEONGNAM: Gimhae, on *Pseudocydonia sinensis*, 21 Jul 2002, *Hye Young Yun, HKFRI 2909*; *HKFRI 2033*; Jinhae, on *Chaenomeles speciosa*, 1 Aug 1984, *Seung Kyu Lee, HKFRI 223*; *HKFRI 224*; Jinju, on *Juniperus chinensis*, 30 Apr 1999, *Seung Kyu Lee, HKFRI 430*. INCHEON: Nam-gu, on *Juniperus chinensis*, 14 Apr 2001, *Hye Young Yun, HKFRI 2009*. JEJU: Jeju-si, on *Juniperus chinensis* cv. *kaizuka*, 13 Apr 2001, *Hye Young Yun, HKFRI 2012*. JEONBUK: Gochang-gun on *Juniperus chinensis*, 20 Apr 2000, *Seung Kyu Lee, HKFRI 483*; Imsil-gun, on *Chaenomeles speciosa*, 29 Jun 1999, *Seung Kyu Lee, HKFRI 225*; on *Pyrus ussuriensis* 11 Jun 1987, *Seung Kyu Lee, HKFRI 738*; 24 Jun 1988, *Seung Kyu Lee, HKFRI 739*; Jeonju, on *Juniperus chinensis*, 20 Apr 2000, *Seung Kyu Lee, HKFRI 452*; on *Juniperus chinensis*, 20 Apr 2000, *Kyoung Hee Kim, HKFRI 466*. JEONNAM: Suncheon, on *Chaenomeles speciosa*, 11 Jul 2002, *Hye Young Yun, HKFRI 2937*. SEOUL: Dongdaemun-gu, on *Chaenomeles speciosa*, 6 Jun 1986, *Hye Young Yun, HKFRI 229*; on *Chaenomeles speciosa*, 5 Jun 1986, *Kyoung Hee Kim, HKFRI 222*; on *Pseudocydonia sinensis*, 28 Jun 1999, *Seung Kyu Lee, HKFRI 238*; on *Pseudocydonia sinensis*, 6 Jul 1999, *Seung Kyu Lee, HKFRI 239*; on *Pseudocydonia sinensis*, 18 Jul 1995, *Kyoung Hee Kim, HKFRI 871*; 2 Aug 1996, *Seung Kyu Lee, HKFRI 872*; 8 Jul 1999, *Kyoung Hee Kim, HKFRI 1140*; on *Pyrus ussuriensis* var. *seoulensis*, 5 Jun 1996, *Seung Kyu Lee, HKFRI 760*; 28 Jun 1999, *Kyoung Hee Kim, HKFRI 761*; on *Juniperus chinensis*, 2 Apr 2000, *Seung Kyu Lee, HKFRI 2016*; 24 Apr 2000, *Seung Kyu Lee, HKFRI 497*; on *Juniperus chinensis* cv. *kaizuka*, 4 May 1996, *Seung Kyu Lee, HKFRI 506*; on *Pseudocydonia sinensis*, 13 Jun 1996, *Seung Kyu Lee, HKFRI 749*. Yeongdeungpo-gu, on *Juniperus chinensis*, 24 Apr 2000, *Seung Kyu Lee, HKFRI 2014*; Gwanak-gu, on *Juniperus chinensis*, 5 Apr 2000, *Seung Kyu Lee, HKFRI 491*; Nowon-gu, on *Juniperus chinensis*, 4 May 2000, *Seung Kyu Lee, HKFRI 1782*; on *Pseudocydonia sinensis*, 6 Jun 1999, *Kyoung Hee Kim, HKFRI 753*; on *Pseudocydonia sinensis*, 2 Jul 2001, *Hye Young Yun, HKFRI 2028*; on *Pyrus ussuriensis*, 2 Jul 2001, *Hye Young Yun, HKFRI 2036*.

Remarks. Hiratsuka et al (1992) and Kern (1973) described the aecia as foliicolous and the telia as foliicolous or on twigs. However specimens of aecia and telia in Korea were found on green stems thus this species also is considered caulicolous. Newly observed telia characteristics include the conical shape on witches' broom and aggregated, bluntly conical telia on green stems (Yun et al 2005). *Gymnosporangium asiaticum* has been confused with *G. unicorne* described below; reports of *G. asiaticum* on *Crataegus* (Chung et al 1977, Korean Soc Plant Prot 1986) most likely refer to *G. unicorne*.

The type specimens of the synonymous names of *G. asiaticum* listed by Kern (1973) were examined to determine whether they could serve as the epithet for the newly recognized segregate species. Each name is detailed below.

Gymnosporangium haraeanum Syd. & P. Syd., *Ann. Mycol.* 10:405, 1912. Lectotypus (hic designatus): JAPAN. MINO: Kawanye-Mura, on *Juniperus chinensis*, 3 Oct 1912, *K. Hara* BPI 119480 determined to be *G. asiaticum*.

The type collection of *Gymnosporangium haraeanum* was distributed in Sydow's Fungi Exotici Exsiccati 16. One of these at BPI was examined and is designated here to serve as the lectotype for this name. This specimen along with two other specimens labeled *G. haraeanum*, one of which is probably from the same collection, were determined to be *G. asiasticum* based primarily on the telia spore size and the aggregated, bluntly conical, foliicolous telia.

Additional specimens examined: JAPAN. MINO: Kawanye-Mura, on *Juniperus chinensis*, *K. Hara*, BPI 119475; TOKYO: Inokashira Park, on *Juniperus chinensis*, 29 Apr 1953, *Hiratsuka T.*, BPI 119478.

Gymnosporangium chinense Long, *J. Agr. Research* 1:354, 1914. Lectotypus (hic designatus): USA. CONNECTICUT: on *Juniperus chinensis*, 28 Mar 1911, *P. Spaulding*, BPI 119487 (labeled '*haraeanum*') determined to be *G. asiaticum*.

Gymnosporangium chinense was described from collections intercepted in Connecticut, USA. Eight specimens matching the protolog were found (BPI

←

2028). G–I. *Gymnosporangium clavariiforme*. G. Telia on *J. rigida* (HKFRI 2080). H. Teliospores (HKFRI 2080). I. Surface structures of peridia cells on *Crataegus pinnatifida* by SEM (HKFRI 1075). J–K. *Gymnosporangium sabinae*. J. Telia on *J. chinensis* cv. *kaizuka* (HKFRI 2104). K. Teliospores on *J. chinensis* by LM (HKFRI 2104). L. *Gymnosporangium japonicum*, telia on *J. chinensis* (HKFRI 1988). Bars: C = 30 μm, F = 5 μm, H = 50 μm, I = 10 μm, K = 20 μm.

119472, BPI 119474, BPI 119487, BPI 119750, BPI 119745, BPI 854938, BPI 854937 and BPI 856627). One of these contained a note with a typed description for "*Gymnosporangium chirrensis* n. sp." and a label for "*Gymnosporangium chinensis* n. sp." This specimen is selected to serve as the lectotype because it most likely was used in the original circumscription of *G. chinense*. Based on the examination of the lectotype and authentic additional material, *G. chinense* is confirmed as a synonym of *G. asiaticum*.

Additional specimens examined: USA. CONNECTICUT: Elm City, near Westville, on *Juniperus chinensis*, 28 Mar 1911, *G.P. Clinton*, BPI 856627 (labeled *haraeanum*); Westville. Elm City Nursery, on *Juniperus chinensis*, 28 Mar 1911, *G.P. Clinton*, BPI 119472 (labeled *haraeanum*); Westville. Elm City Nursery, on *Juniperus chinensis*, 28 Mar 1911, *G.P. Clinton*, BPI 119474 (labeled *haraeanum*).

The remaining specimens contained only *Gymnosporangium japonicum* and are listed below under that species.

Gymnosporangium koreaense (Henn.) H.S. Jacks., *J. Agr. Research* 5:1006, 1916.

≡ *Roestelia koreansis* Henn., *O. Warburg, Monsunia* 1:5, 1899. Lectotypus (hic designatus): KOREA: on *Pinus* sp., *O. Warburg*, BPI 856647.

Gymnosporangium koreaense was given as a new combination for *Roestelia koreansis* Henn. This must be treated as a new combination based on the anamorph type because it lacks a diagnosis and therefore does not meet the requirements for valid publication of a new species, under ICBN Article 59. Thus the type of *G. koreaense* is the same as that of *R. koreansis*. Part of the type specimen of *R. koreansis* was examined and is designated the lectotype. An additional portion exists at NY. This lectotype specimen as well as the material cited in Jackson (1916) represents *G. asiaticum*.

Additional specimens examined: USA. OREGON: Multnomah County, Portland, on *Juniperus chinensis*, 29 MAR 1915, *H.S. Jackson*, BPI 119479; on *Juniperus chinensis*, 29 MAR 1915, *H.S. Jackson*, BPI 119485; on *Juniperus chinensis*, 29 MAR 1915, *H.S. Jackson*, BPI 856635; on *Pyrus ussuriensis*, 11 Jun 1914, *H.S. Jackson*, BPI 121785; on *Pyrus ussuriensis*, 11 Jun 1914, *H.S. Jackson*, BPI 121786.

Gymnosporangium spiniferum Syd. & P. Syd., Ann. Mycol. 10:78, 1912. Type specimen examined: JAPAN: on *Cydonia oblonga*, 20 Jun 1901, *K. Sakurai*, BPI 112834.

Gymnosporangium spiniferum was described from its aecia state and can be applied only as an anamorph. Because duplicates of type material exist one of these herein is designated as the lectotype. Based on the examination of the lectotype and additional material, *G. spiniferum* is confirmed as a synonym of *G. asiaticum*.

Gymnosporangium clavariiforme (Pers.) DC. in Lamarck & de Candolle, Fl. franç., Ed 3 (Paris) 2:217, 1805. FIG. 5

≡ *Tremella clavariiformis* Pers. 1801.

Aecia foliicolous, hypophyllous, fructicolous, and caulicolous, in small groups on leaf blades, in larger groups on veins, petioles and on swellings of twigs, and occupying part or all of surface on fruits. Peridium tubular, soon becoming lacerate to base, erect or spreading, 0.5–1.8 mm high; peridial cell long, narrow, 83–125 μm, outer walls smooth, inner walls and side walls sparsely echinulate; aeciospores globose, echinulate, 22–32 × 19–28 μm, wall light brown, 1.8–3.2 μm.

Telia caulicolous, on long fusiform swellings, orange or brown, 2–10 mm high; teliospores 2-celled, narrowly fusiform, 38–99 × 13–23 μm, pale orange, 1.4–2.3 μm; pores 2 near septum.

Disease. European hawthorn rust.

Hosts in Korea. O, I: *Crataegus pinnatifida* Bunge. III: *Juniperus rigida* Sieb. & Zucc.

Distribution. Relatively common in temperate regions, especially in Europe and North America, but also known from northern Africa (Morocco), the Middle East (Iraq), Nepal, Pakistan, New Zealand, and previously but infrequently reported from China, Japan and Korea. In Korea *G. clavariiforme* was uncommon, found only in Jeonbuk and Seoul provinces (FIG 1).

Specimens examined. CANADA. BRITISH COLUMBIA: on *Crataegus rhipidophylla*, 23 Aug 1949, *DAOM 23364*; on *Crataegus rhipidophylla*, Aug 1939, *DAOM 5931*. KOREA. JEONBUK: Muju-gun, on *Crataegus pinnatifida*, 2 Sep 1999, *Seung Kyu Lee, HKFRI 308*. SEOUL: Dongdaemun-gu, on *Crataegus pinnatifida*, 18 Jun 1985, *Seung Kyu Lee, HKFRI 873*; 11 Aug 1999, *Hye Young Yun, HKFRI 2052*; 6 Aug 1986, *Seung Kyu Lee, HKFRI 1075*; Yeongdeungpo-gu, on *Juniperus rigida*, 10 Apr 2002, *Hye Young Yun, HKFRI 2080*. SWEDEN. on *Juniperus communis*, Mar 1936, *HKFRI S411*.

Remarks. Chung (1977) had listed *Crataegus pinnatifida* var. *psiloda* as an aecia host of *Gymnosporangium clavariiforme*. In the present study *C. pinnatifida* is added as an aecia host of this fungus in Korea.

Gymnosporangium globosum (Farl.) Farl., Bot. Gaz. 11:239, 1886. FIG. 6

≡ *Gymnosporangium fuscum* var. *globosum* Farl. 1880.

Aecia foliicolous, mainly hypophyllous, 2–4 mm high; peridium cylindrical, splitting above and becoming lacerate, more or less erect after dehiscence; peridial cells linear rhomboidal, 60–90 μm long, inner and side walls 3–4 μm thick, outer walls smooth, inner walls small papillae and side walls rugose; aeciospores globose or broadly ellipsoid, small coro-

nate, 19–27 × 16–20 μm, wall 1.8–2 μm thick, pale chestnut brown.

Disease. American hawthorn rust.

Hosts in Korea. O, I: *Crataegus pinnatifida* Bunge, *Crataegus pinnatifida* var. *major* N.E. Br.

Distribution. Common in North America on *Crataegus*, also known on *Amelanchier*, *Malus*, *Pyrus* and *Sorbus* as well as *Juniperus*; recently reported from Korea on *Crataegus* (Yun et al 2008).

Specimens examined. CANADA. ONTARIO: on *Crataegus brunetiana*, 10 Sep 1975, *DAOM 151699*; OTTAWA: on *Crataegus pedicellata*, 8 Sep 1952, *DAOM 34124*. KOREA. CHUNGBUK: Boeun-gun, on *Crataegus pinnatifida* var. *major*, 24 Jun 1985, *Kyoung Hee Kim, HKFRI 310*. GYEONGGI: Pocheon-gun, on *Crataegus pinnatifida*, 8 Jul 1999, *Seung Kyu Lee, HKFRI 304*; Osan, on *Crataegus pinnatifida*, 19 Jun 1986, *Seung Kyu Lee, HKFRI 1074*. USA. VERMONT: on *Crataegus coccinea*, 28 Sep 1897, *BPI 119014*. OHIO: 16 Aug 1902, *F.D. Kelsey, BPI 119042*.

Remarks. Gymnosporangium globosum first was reported from Korea on the aecia hosts *Crataegus pinnatifida* and *C. pinnatifida* var. *major* by Yun et al (2008).

Gymnosporangium japonicum Shirai, Hedwigia 38:141, 1899. FIG. 6

Aecia foliicolous and caulicolous, hypophyllous, 2–5 mm high. Peridium dehiscent at apex, retaining somewhat tubular shape; peridial cells linear rhomboid, 62–117 μm long, outer walls smooth, inner and side walls sparsely echinulate; aeciospores globose, 20–26 × 16–21 μm, walls dark yellow, 1.1–2.8 μm thick, small coronate.

Telia caulicolous, on woody stems, branches and trunks, irregularly wedge-shaped, 3–6 mm high, brownish orange; teliospores 2-celled or rarely 3-celled, ellipsoid to long-ellipsoid, 36–70 × 13–22 μm, walls pale orange to orange, rarely light brown, 1.0–2.7 μm thick, usually pores 1 or 2 near septum.

Disease. Asian juniper trunk rust.

Hosts in Korea. O, I: *Photinia villosa* (Thunb.) DC., *P. villosa* var. *brunnea* Nakai. III: *Juniperus chinensis* L., *J. chinensis* var. *horizontalis* Nakai; *J. chinensis* var. *sargentii* A. Henry, *J. chinensis* var. *globosa* Hornibr.

Distribution. Asia (China, Japan, Korea and Taiwan) and USA (rarely reported, then primarily on newly imported nursery stock).

Specimens examined. CHINA. on *Photinia parvifolea*, 26 Jun 1932, *HMAS 11147*. JAPAN. TOFFORI: on *Photinia laevis* var. *villosa*, 22 Jun 1934, *SAPA 14*; 21 Jun 1934, *SAPA 5*. KOREA: GANGWON: Gangneung, on *Juniperus chinensis*, 9 Apr 1988, *Seung Kyu Lee, HKFRI 504*. GYEONGBUK: Gyeongju, on *Juniperus chinensis* var. *sargentii*, 12 Apr 2002, *Kyoung Hee Kim, HKFRI 1991*. GYEONGGI: Suwon, on *Juniperus chinensis*, 31 Mar 2002, *Hye Young Yun, HKFRI 1989*; on *Juniperus chinensis*, 13 Apr 2001, *Hye Young Yun, HKFRI 1992*; 20 Apr 2001, *Hye Young Yun, HKFRI 2070*; on *Juniperus chinensis* var. *horizontalis*, 20 Apr 2001, *Hye Young Yun, HKFRI 2020*. JEJU: Jeju-si, on *Photinia villosa* var. *brunnea*, 29 Aug 2001, *Hye Young Yun, HKFRI 2090*; *HKFRI 2091*; *HKFRI 2093*; on *Photinia villosa*, 13 Jul 1999, *Seung Kyu Lee, HKFRI 694*; on *Photinia villosa*, 29 Jul 1999, *Seung Kyu Lee, HKFRI 695*; on *Photinia villosa*, 29 Aug 2001, *Hye Young Yun, HKFRI 142*; *HKFRI 144*; *HKFRI 145*; *HKFRI 147*; on *Photinia villosa*, 29 Aug 2001, *Hye Young Yun, HKFRI 148*; on *Photinia villosa*, 23 Aug 2001, *Hye Young Yun, HKFRI 2054*; on *Juniperus chinensis* var. *sargentii*, 19 Apr 2001, *Seung Kyu Lee, HKFRI 2019*; on *Juniperus chinensis* var. *sargentii*, 9 Apr 2002, *Hye Young Yun, HKFRI 1990*, *HKFRI 1994*; 19 Apr 2002, *Seung Kyu Lee, HKFRI 1996*; on *Juniperus chinensis* var. *globosa*, 9 Apr 2002, *Seung Kyu Lee, HKFRI 1997*; on *Juniperus chinensis* var. *horizontalis*, 9 Apr 2001, *Seung Kyu Lee, HKFRI 1993*: on *Juniperus chinensis* var. *horizontalis*, 19 Apr 2002, *Seung Kyu Lee, HKFRI 1995*; on *Juniperus chinensis*, 9 Apr 2002, *Seung Kyu Lee, HKFRI 1987*; 19 Apr 2001, *Seung Kyu Lee, HKFRI 2021*. SEOUL, Dongdaemun-gu, on *Juniperus chinensis*, 19 Apr 2002, *Hye Young Yun, HKFRI 1988*; on *Juniperus chinensis*, 16 Apr 2000, *Seung Kyu Lee, HKFRI 1784*; on *Photinia villosa*, 20 Jun 2001, *Hye Young Yun, HKFRI 2055* (result of teliospore inoculation of *G. japonicum*: *HKFRI 2019*). on *Photinia villosa*, 20 Jun 2001, *Hye Young Yun, HKFRI 2056* (result of teliospore inoculation of *G. japonicum*: *HKFRI 2020*; Yun et al 2005). USA. CONNECTICUT: Westville, on *Juniperus chinensis*, 28 Mar 1911, *P. Spaulding*, BPI 119750; Westville, near Elm City, on *Juniperus chinensis*, 28 Mar 1911, *G.P. Clinton*, BPI 119745 (most of this specimen was *G. japonicum*, although *G. asiaticum* was also present); Westville, Elm City Nursery, on *Juniperus chinensis*, 28 Mar 1911, *G.P. Clinton*, BPI 854938; Westville, Elm City Nursery, on *Juniperus chinensis*, 28 Mar 1911, *G.P. Clinton*, BPI 854937; WASHINGTON: on *Juniperus* sp., 3 May 1915, *G.R. Lyman*, BPI 119741.

Remarks. Gymnosporangium japonicum occurs primarily in Japan and only recently was reported from Korea (Yun et al 2003). Six host species of *G. japonicum* were reported for the first time in Korea by Yun et al (2003), namely *Photinia villosa* and *P. villosa* var. *brunnea* as aecia hosts and *Juniperus chinensis*, *J. chinensis* var. *horizontalis*, *J. chinensis* var. *sargentii* and *J. chinensis* var. *globosa* as telia hosts. In Korea these two host species usually grow in separate locations and thus the heteroecious hosts for this fungus are normally disjunct.

Gymnosporangium monticola H.Y. Yun sp. nov. FIG. 6
MycoBank MB 512678

Etymology. Refers to mountains where this species occurs.

Spermogonia et aecia foliicola, et fortasse fruticola, roestelioida. Peridium cornutum, 0.5–2.5 mm altum; cellulae peridii rotundatae rhomboides, 48–101 μm longae. Aeciosporae globosae, 18–28 × 17–27 μm, minute coronatae. Telia caulicola, tumores irregulariter fusiformes in

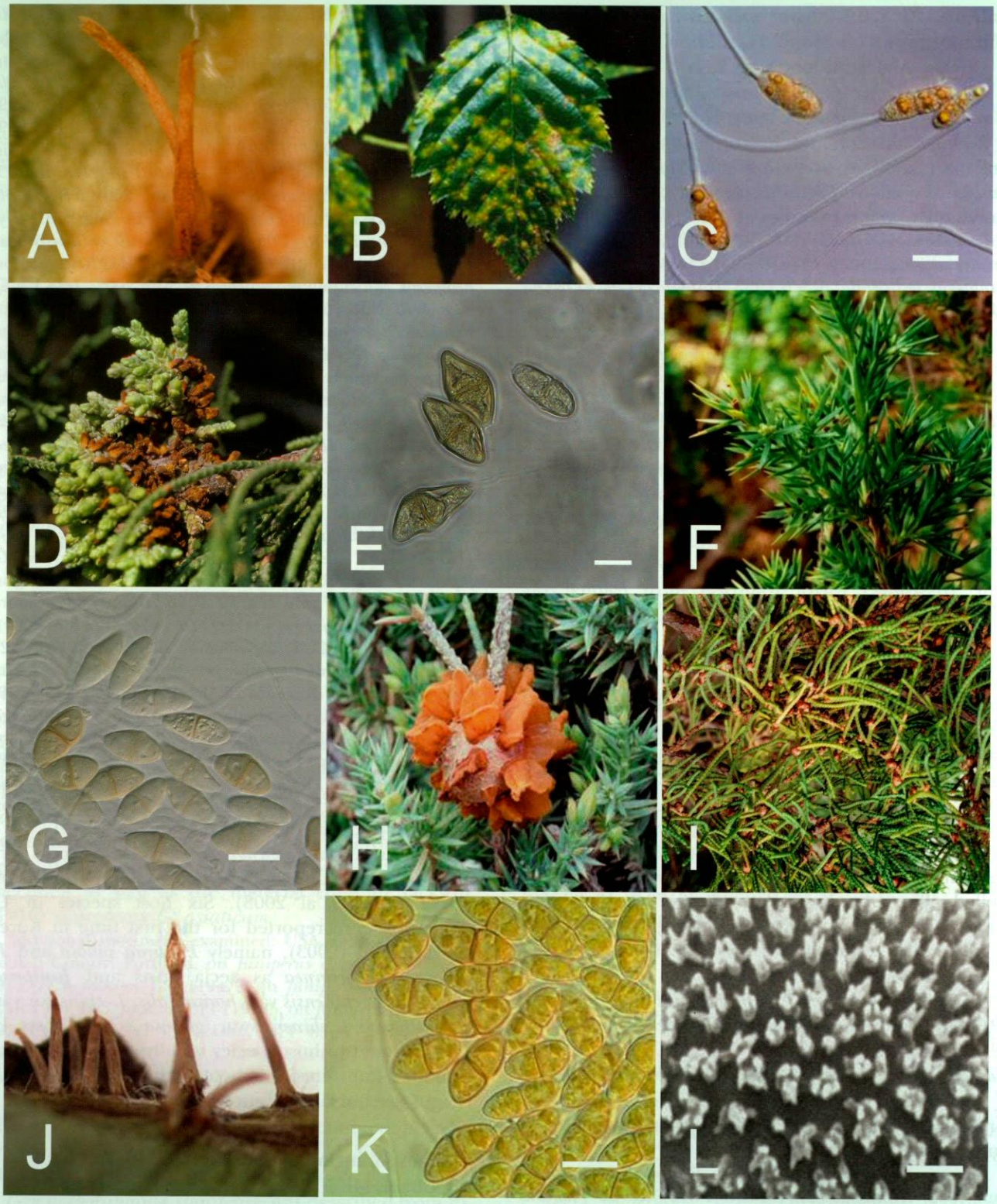

FIG. 6. Macroscopic and microscopic features of *Gymnosporangium japonicum, G. globosum, G. monticola, G. nidus-avis, G. unicorne* and *G. yamadae.* A. *Gymnosporangium japonicum,* artificially induced aecia on *Photinia villosa* (HKFRI 2054). B–C. *Gymnosporangium monticola.* B. Artificially induced spermogonia on *Sorbus alnifolia* (HKFRI 2053). C. Teliospores by LM (HKFRI 2018). D–E. *Gymnosporangium nidus-avis.* D. Telia on *Juniperus chinensis* cv. *kaizuka* (witches' broom) (HKFRI 2103). E. Teliospores by LM (HKFRI 2103). F–G. *Gymnosporangium unicorne.* F. Telia on *J. chinensis* var. *sargentii* (HKFRI 1973). G. Teliospores by LM (HKFRI 1973). H–L. *Gymnosporangium yamadae.* H. Telia on *J. chinensis* (big gall, sori tongue-shape)

ramis parvulis fascientia, applanata vel pulvinata; teliosporae 2(–3)-cellulares, late ellipsoideae, 36–63 × 16–29 μm.

HOLOTYPE: KOREA. GYEONGGI: Gwacheon, telial stage on *Juniperus rigida*, 10 Apr, 2001, *Hye Young Yun*, HKFRI 2018.

Spermogonia and aecia foliicolous, fructicolous, roestelioid, causing some hypertrophy. Peridium cornuted, rupturing at apex, becoming lacerate but retaining tubular form, 0.5–2.5 mm high; peridia cells rounded rhomboidal, 48–101 μm long, outer cell smooth, side cells moderately rugose, inner cell small papillae; aeciospores globose, 18–28 × 17–27 μm, walls yellow-brown, 1.3–2.5 μm thick, minutely coronate.

Telia caulicolous, forming irregularly fusiform swellings of smaller branches, applanate or pulvinate, dark brown, 10–60 mm × 10–12 mm, covering branch; teliospores 2-celled, rarely 3-celled, broadly ellipsoid, 36–63 × 16–29 μm, walls orange, regularly thin-walled, 1.4–2.8 μm thick, 1–2 pores near septum or 1 apical in upper cell and covered ellipsoid with hyaline papillae.

Disease. Mountain juniper rust.

Hosts in Korea. O, I: *Sorbus alnifolia* (Siebold & Zucc.) K. Koch I II: *Juniperus rigida* Siebold & Zucc.

Distribution. Known from four localities in Korea.

Additional specimens examined. KOREA. CHUNGBUK: Boeun-gun, on *Sorbus alnifolia*, 15 Jul 1999, *Seung Kyu Lee, HKFR I 931*. GYEONGGI: Gwacheon, on *Juniperus rigida*, 10 Apr 2001, *Hye Young Yun, HKFRI 2018*; 6 Apr 2000, *Seung Kyu Lee, HKFRI 1794*; on *Juniperus rigida*, 15 Apr 2000, *Seung Kyu Lee, HKFRI 1792*; 22 Apr 2000, *Seung Kyu Lee, HKFRI 1793*; 22 Apr 2000, *Seung Kyu Lee, HKFRI 1788*; on *Juniperus rigida*, 3 May 2001, *Hye Young Yun, HKFRI 1985*; 28 Mar 2002, *Hye Young Yun, HKFRI 1984*. SEOUL: Gwanak-gu, on *Sorbus alnifolia*, 8 Jul 2000, *Hye Young Yun, HKFRI 2071*; on *Juniperus rigida*, 5 May 2000, *Seung Kyu Lee, HKFRI 517*; *Kyoung Hee Kim, HKFRI 518*; *HKFRI 519*; *HKFRI 520*; Nowon-gu, on *Sorbus alnifolia*, 20 Jun 1998, *Seung Kyu Lee, HKFRI 928*; *HKFRI 935*; 20 Jun 2000, *Hye Young Yun, HKFRI 2053* (result of teliospore inoculation of *G. monticola*; *HKFRI 2018*; Yun et al 2005).

Remarks. Gymnosporangium monticola initially was reported as *Gymnosporangium cornutum* (Yun et al 2003) because of the similarity in host range, surface structure of aeciospores and peridial cells, and number of pores in the teliospores. However the sizes of aecia and peridial cells of *G. monticola* are smaller than those of *G. cornutum* (Kern 1973, Hiratsuka et al 1992). The aecia of *G. monticola* are 0.5–2.5 mm high, while those of *G. cornutum* are 3–5 mm high. In addition the teliospores of *G. monticola* have 2, rarely 3 cells, and are longer than those of *G. cornutum*. The aecia and telia hosts of *G. monticola* are found in mountainous areas. The telia host of *G. cornutum* is *Juniperus communis* and its varieties, while *G. monticola* occurs on *J. rigida*. The aecia host, *Sorbus alnifolia*, is native to Korea in the mountains at 100–1300 m elevation. Similarly the telia host, *Juniperus rigida*, occurs at 40–1100 m. Finally results of the molecular sequence analysis demonstrate that the Korean specimens originally identified as *G. cornutum* are distinct from those in Germany and Japan thus the Korean specimens are described as a new species. True *G. cornutum* is not known to occur in Korea.

Several other species of *Gymnosporangium* with roestelioid aecia on *Sorbus* could be confused with *G. monticola*. These include *Gymnosporangium clavariiforme*, *G. claviceps*, *G. globosum*, *G. miyabei*, *G. torminali-juniperinum*, *G. tremelloides* and *G. turkestanicum*. All but *G. globosum*, *G. torminali-juniperinum* and *G. tremelloides* differ in the lack of rugose ornamentation on the peridia cell walls. Although the aecia of *G. globosum* occur on *Sorbus*, the telia host infects species in *Juniperus* section *Sabina*. *Gymnosporangium torminali-juniperinum* has aecia 2–5 mm high, foliicolous telia and lacks 3-celled teliospores unlike *G. monticola*. Among species that occur on *Juniperus* section *Oxycedrus*, *G. confusum* differs from *G. monticola* in telia shape and size while G. *tremelloides* has larger aeciospores than *G. monticola*.

Although morphologically similar, *G. cornutum* and *G. monticola* are not phylogenetically closely related. The two isolates of *G. cornutum* that were sequenced from Japan and Germany grouped together but were distant from sequences of *G. monticola*.

Gymnosporangium nidus-avis Thaxt., Conn. Agr. Exp. Sta. Bull. 107:6 (1891). FIG. 6

= *Gymnosporangium juvenescens* F. Kern (1911).

Telia usually caulicolous, rarely foliicolous, hemispherical on witches' broom, pulvinate, on fusiform swellings of woody stems, 2–5 mm high, brownish orange; teliospores 2-celled, ellipsoid or ovoid, 41.0–55.5 × 18.0–26.5 μm, wall 1–2.5 μm, pale brown, known as orange peel based on Kornerup and Wanscher (1978), pores 2 septum and rarely 1 apical in upper cell.

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(HKFRI 2001). I. Telia on *J. chinensis* cv. *kaizuka* (small gall, sori cylindric-acuminate) (HKFRI 2006). J. Artificial aecia on *Malus toringo* (HKFRI 2069). K. Teliospores (HKFRI 2001). L. Surface structures of the aeciospores on *M. prunifolia* (HKFRI 2063). Bars: C = 30 μm, E = 20 μm, G = 30 μm, K = 30 μm, L = 1 μm.

Disease. Juniper broom rust.

Hosts in Korea. Juniperus chinensis L.

Distribution. Temperate North America, also rarely in Asia (China, Korea).

Specimens examined. KOREA. CHUNGBUK: Boeun, on *Juniperus chinensis*, 25 Apr 2005, *Hye Young Yun, HKFRI 2103.* SEOUL: Yeongdeungpo-gu, on *J. chinensis*, 15 Apr 2005, *Hye Young Yun, HKFRI 2101*; *HKFRI 2102.*

Remarks. Gymnosporangium nidus-avis was found in Seoul and Chungbuk provinces and is a newly reported species in Korea. This fungus previously was reported only in northeastern China (Wang and Lin 1985).

Gymnosporangium sabinae (Dicks.) G. Winter, Rabenhorst's Kryptogamen-Flora, Pilze-Schizomyceten, Saccharomyceten und Basidiomyceten 1(1):232, 1881. FIG. 5

≡ *Tremella sabinae* Dicks. 1785.

[*Gymnosporangium fuscum* DC. 1805, nom. illeg.]

= *Puccinia juniperi* Pers.: Pers. 1794.

Telia caulicolous, fusiform swellings, conical or tongue-shaped, variable, 4–7 mm high, brownish orange; teliospores 2-celled, brownish orange, 38–51.5 × 18.5–25 μm, walls 1.5–2 μm thick.

Disease. European pear rust, pear trellis rust.

Hosts in Korea. Juniperus chinensis L.

Distribution. This fungus is widespread in Europe and extends to Asia (China, Korea) and northern Africa (Algeria, Morocco). Also introduced into North America (Canada and USA) (Laundon 1977b, CMI 1989).

Specimens examined. KOREA. GYEONGNAM: Geochang, on *Juniperus chinensis*, 11 May 2006, *Hye Young Yun, HKFRI 2104.* USA. CALIFORNIA: on *Juniperus chinensis*, 26 Feb 1961, *C.G. Weigle, BPI 118494.*

Remarks. Gymnosporangium sabinae is reported herein as new to Korea, known only in Gyeongnam Province. This fungus was reported in China by Wang and Lin (1985); it is not known in Japan.

Gymnosporangium unicorne H.Y. Yun sp. nov. FIG. 6
MycoBank MB 512679

Etymology. Refers to the single horn-shaped telia.

Aecia foliicola, 1–7.2 mm alta, cornuta; peridium apicem versus leviter decrescens; cellulae peridii rhomboides, rugosae papillis irregulariter obtusis, 32.5–80.5 μm longae. Aeciosporae irregulariter vel regulariter globosae, 14.5–24 × 13–23.5 μm, late coronatae. Telia foliicola, non tumores fascientia, solitaria, hemisphaerii forma vel acute conica 0.8–2 mm alta; teliosporae 2-cellulares, fusiformes, 31–47 × 15–23 μm.

HOLOTYPE: KOREA. SEOUL: Dongdaemun-gu, on *Juniperus chinensis* var. *globosa*, 12 Apr, 2001, *Hye Young Yun, HKFRI 1972.*

Aecia foliicolous, 1–7 mm high, cornute; peridium narrowing slightly toward apex. Peridial cells rhomboid, rugose with irregular blunt papillae, 32.5–80.5 μm long, pale yellowish; outer walls smooth, inner walls small papillate, and side walls moderately rugose; aeciospores irregularly shaped, globose or globose, large coronate, 14.5–24 × 13–23.5 μm, yellow to orange-yellow 1.5–3.5 μm thick.

Telia foliicolous, not causing hypertrophy, solitary, hemispherical to sharply conical 0.8–2 mm high; brownish orange to red brown; teliospores 2-celled, fusiform, 31–47 × 15–23 μm, L:W = 2.0, walls 0.8–2.5 μm thick, orange, pores 1 or 2 near septum or 1 apical pore in upper cell.

Disease. Unicorn telia rust.

Hosts in Korea. O, I on *Crataegus pinnatifida* Bunge, *Chaenomeles speciosa* (Sweet) Nakai, *Pseudocydonia sinensis* (Thouin) C. K. Schneid., *Pyrus pyrifolia* (Burm. f.) Nakai var. *culta* (Makino) Nakai, *Pyrus ussuriensis* Maxim. III on *Juniperus chinensis* L. var. *globosa* Hornibr., *Juniperus chinensis* var. *sargentii* A. Henry.

Distribution. Korea (Chungnam and Seoul provinces).

Additional specimens examined. KOREA. CHUNGNAM: Cheonan, on *Juniperus chinensis* var. *sargentii*, 12 Apr 2002, *Hye Young Yun, HKFRI 1973.* SEOUL: Dongdaemun-gu, on *Juniperus chinensis* var. *globosa*, 11 Apr 2002, *Hye Young Yun, HKFRI 1971*; on *Crataegus pinnatifida* 4 Jul 2001, *Hye Young Yun, HKFRI 2044*; *HKFRI 2051* (Both of these specimens are the result of teliospore inoculation, Yun et al 2005); on *Chaenomeles speciosa* 14 Jun 2001, *Hye Young Yun, HKFRI 2042*; *HKFRI 2043*; *HKFRI 2049*; *HKFRI 2050* (These specimens are the result of teliospore inoculation, Yun et al 2005); on *Pseudocydonia sinensis* 2 Jul 2002, *Hye Young Yun, HKFRI 2071* (This specimen is the result of teliospore inoculation, Yun et al 2005); on *Pyrus pyrifolia* var. *culta*, 17 Aug 2001, *Hye Young Yun, HKFRI 2033*; *HKFRI 2034*; *HKFRI 2035*; *HKFRI 2038*; *HKFRI 2039*; *HKFRI 2045*; *HKFRI 2046* (These specimens are the result of teliospore inoculation, Yun et al 2005); on *Pyrus ussuriensis*, 2 Jul 2001, *Hye Young Yun, HKFRI 2036*; *HKFRI 2037*; *HKFRI 2040*; *HKFRI 2041*; *HKFRI 2047*; *HKFRI 2048* (These specimens are the result of teliospore inoculation, Yun et al 2005).

Remarks. Gymnosporangium unicorne is related to *G. asiaticum*; however these species can be differentiated by the telia shape, size of teliospores, peridial cells and aeciospores. The telia of *G. unicorne* are unique in being single, sharply conical or hemispherical. The teliospores of *G. unicorne* are smaller and more rounded, having a length-width ratio of 2.0, while those of *G. asiaticum* tend to be longer and narrower with a length-width ratio of 2.3. *Gymnosporangium unicorne* occurs only on the needle-like and scale-like leaves of *Juniperus* growing low to the ground. The molecular data presented here support the recognition of *G. unicorne* as distinct from *G. asiaticum.*

The aecia stage of *Gymnosporangium unicorne* was not found in nature; however rosaceous hosts artificially inoculated with teliospores from the

holotype specimen produced the aecia stage (Yun et al 2005 as *G. asiaticum* GA-2 and GA-3). The aecia hosts of *G. unicorne* are similar to those of *G. asiaticum* except only *G. unicorne* infects *Crataegus* spp. Molecular sequence data from the telia holotype specimen of *G. unicorne* matched sequence data from isolates obtained from inoculation studies.

A number of synonyms of *Gymnosporangium asiaticum* could serve as potential names for this newly recognized species, according to Kern (1973). These include *G. haraeanum*, *G. chinense*, *G. koreaense* and *G. spiniferum*. Type specimens for each of these epithets were examined as detailed under *G. asiaticum*, and none were determined to represent the new species, *G. unicorne*.

Gymnosporangium yamadae Miyabe ex G. Yamada, Shokubutse Byorigaku (Pl. Path) Tokyo Hakubunkwan 37(9):306, 1904. FIG. 6

[= *Gymnosporangium chinensis* S. Ito, illeg. later homonym]

[= *Gymnosporangium yamadae* (Miyabe) F. Kern 1911]

Aecia foliicolous and caulicolous, hypophyllous, 2–5 mm high. Peridium elongated, cornute, becoming lacerate, remaining attached at apex, peridial cells long-narrow rhomboid 63–102 μm long, verrucose with long papillae, outer walls smooth, inner and side walls sparsely echinulate; aeciospores globose, 17–27 × 16–26 μm, walls dark yellow, 1.5–2.5 μm thick, finely echinulate.

Telia foliicolous, or caulicolous, on globose swellings, small galls, sori cylindrical-acuminate, 1–3 mm diam, big gall, sori tongue-shaped, 5–9 mm high or higher, cadmium orange; teliospores 2-celled, ellipsoid or obovoid, 31–56 × 15–28 μm, walls 1.0–2.7 μm, pale orange to orange, pores 2 near septum or 1 apical in upper cell, frequently with an obtuse hyaline papilla at apex.

Disease. Japanese apple rust.

Hosts in Korea. O, I: *Malus baccata* (L.) Borkh., *Malus toringo* (Siebold) Siebold ex de Vriese, *M. prunifolia* (Willd.) Borkh. III: *Juniperus chinensis* L., *J. chinensis* L. cv. *kaizuka*

Distribution. China, Japan and Korea.

Specimens examined. CHINA. on *Malus* × *asiatica*, 5 Sep 1984, *HMAS 55353*; on *Malus* × *asiatica*, 27 Aug 1947, *HMAS 17707*; HEBEI: on *Malus* × *asiatica*, 17 Aug 1984, *Lin Guo, BPI 199111*; on *Malus pumila*, 2 Aug 1979, *HMAS 38650*; *HMAS 22181*. KOREA. CHUNGBUK: Boeun-gun, on *Malus prunifolia*, 15 Jul 1999, *Seung Kyu Lee, HKFRI 1028*; Muju-gun, on *Juniperus chinensis*, 30 Apr 2000, *Kyoung Hee Kim, HKFRI 2025*. CHUNGNAM: Gongju, on *Malus prunifolia*, 12 Jul 1999, *Seung Kyu Lee, HKFRI 1027*. GANGWON: Chuncheon, on *Malus prunifolia*, 23 Jul 1999, *Seung Kyu Lee, HKFRI 1029*. GYEONGBUK: Andong, on *Juniperus chinensis*, 13 Apr 2000, *Seung Kyu Lee, HKFRI 1798*; 20 Apr 2000, *Seung Kyu Lee, HKFRI 487*; Yeongdeok-gun, on *Juniperus chinensis*,14 Apr 2000, *Seung Kyu Lee, HKFRI 482*. GYEONGGI: Bucheon, on *Juniperus chinensis* cv. *kaizuka*, 8 Apr 2002, *Hye Young Yun, HKFRI 2006*; 19 Apr 2001, *Hye Young Yun, HKFRI 2007*; Buk-gu, Gwangju, on *Malus prunifolia*, 16 Aug 2001, *Hye Young Yun, HKFRI 2067, HKFRI 2068*; Gwacheon, on *Juniperus chinensis*, 15 Apr 2000, *Seung Kyu Lee, HKFRI 503*; on *Juniperus chinensis*, 15 Apr 2000, *Seung Kyu Lee, HKFRI 499*; Osan, on *Malus prunifolia*, 25 Aug 1999, *Kyoung Hee Kim, HKFRI 1032*; 25 Aug 1999, *Kyoung Hee Kim, HKFRI 1034*; Pocheon-gun, on *Juniperus chinensis*, 4 Apr 2000, *HKFRI 492*; on *Malus prunifolia*, 8 Jul 1999, *Seung Kyu Lee, HKFRI 1144*; on *Malus prunifolia*, 6 Aug 1999, *Seung Kyu Lee, HKFRI 1030*; Suwon, on *Malus prunifolia*, 18 Aug 2001, *Hye Young Yun, HKFRI 2058, HKFRI 2059*; on *Malus prunifolia*, 12 Jul 2001, *Hye Young Yun, HKFRI 2063*; on *Malus prunifolia*, 1 Sep 2001, *Hye Young Yun, HKFRI 2060*; on *Malus prunifolia*, 28 Aug 2001, *Hye Young Yun, HKFRI 2061*; 28 Jul 2001, *HKFRI 2065*; on *Juniperus chinensis*,10 Apr 2000, *Seung Kyu Lee, HKFRI 463*; *HKFRI 464*; on *Juniperus chinensis*,10 Apr 2000, *Hye Young Yun, HKFRI 2027*; on *Malus baccata*, 1 Aug 1996, *Seung Kyu Lee, HKFRI 610*; on *Malus toringo*, 3 Aug 1998, *Seung Kyu Lee, HKFRI 617*. JEONBUK: Jeonju, on *Juniperus chinensis*, 20 Apr 2000, *Hye Young Yun, HKFRI 2024*; on *Juniperus chinensis*, 30 Apr 2000, *Kyoung Hee Kim, HKFRI 2026*. JEONNAM: Gangjin-gun, on *Malus prunifolia*, 18 Aug 2001, *Hye Young Yun, HKFRI 2062*. SEOUL: Dongdaemun-gu, on *Malus prunifolia*, 9 Aug 2001, *Hye Young Yun, HKFRI 2064*; *HKFRI 2066*; on *Malus toringo*, 28 Jun 1999, *Seung Kyu Lee, HKFRI 616*; on *Juniperus chinensis*, 24 Apr 2000, *Seung Kyu Lee, HKFRI 496*; Gwanak-gu, on *Juniperus chinensis*, 5 May 2000, *Hye Young Yun, HKFRI 438*; Nowon-gu, on *Juniperus chinensis*, 4 May 2000, *Hye Young Yun, HKFRI 435*; Yeongdeungpo-gu, on *Juniperus chinensis*, 12 Apr 2001, *Hye Young Yun, HKFRI 88*; *HKFRI 2022*; *HKFRI 2023*; on *Juniperus chinensis*, 23 Apr 2002, *Hye Young Yun, HKFRI 2001*; on *Malus baccata*, 2 Aug 2001, *Hye Young Yun, HKFRI 2057*. on *Malus toringo*, 6 Jul 2001, *Hye Young Yun, HKFRI 2069, HKFRI 2070* (result of teliospore inoculation of *G. yamadae*: *HKFRI 88*; Yun et al 2005).

Remarks. One new aecia host of *G. yamadae*, namely *Malus prunifolia*, is reported here for the first time.

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