The Lichen Genus Sticta in South Korea

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Abstract  Sticta (Schreber.) Ach. is one of the common lichen genera in tropical and subtropical regions, but not in the Korean Peninsula. For almost two decades, no detailed taxonomic or revisionary study has been done on this genus. This study was based on the specimens deposited in the lichen herbarium at the Korean Lichen Research Institute, and the samples were identified on the basis of recent literature. In this revisionary study, a total of eight species of Sticta, including a newly recorded one are documented. These species include Sticta fuliginosa (Dicks.) Ach., Sticta gracilis (Müll. Arg.) Zahlbr., Sticta limbata (Sm.) Ach., Sticta nylanderiana Zahlbr., Sticta sublimbata (J. Steiner) Swinscow & Krog, Sticta weigelii (Ach.) Vain., Sticta wrightii Tuck., and Sticta yatabeana Müll. Arg. Detailed descriptions of S. nylanderiana, S. sublimbata, S. weigelii, and S. yatabeana with their morphological, anatomical, and chemical characteristics are provided. A key description of all known Sticta species of the Korean Peninsula is also presented.

Keywords  Foliose, Lobariaceae, Nostoc, South Korea, Sticta

The genus Sticta (Schreber.) Ach. belongs to family Lobariaceae [1]. It is one of the commonest foliose lichens, characterized by the presence of cyphellae on their lower surface [2]. This genus is superficially similar to two genera, namely, Lobaria (Schreber) Hoffm. and Pseudocyphellaria Vain., but is distinguished by the presence of cyphellae [3, 4]. In addition to the presence of cyphellae, this genus is mainly characterized by a lobate thallus, spreading or stalked with an erect monophyllous to polyphyllous frond. The lobes are irregularly branched, rounded to imbricate to variously incised, often lacerate-notched, with or without isidia, soredia, or phylidia [5].

Although the genus Sticta is primarily tropical to subtropical in distribution, its species exist as far north as Norway [6] and as far south as the southern tip of South America [7]. Although Moncada et al. [8] stated that the actual number of existing species is unknown, 190 species have been identified thus far [9]. Monographic revisionary work on the genus Sticta has been carried out in different regions in the world [4, 7, 8, 10-13].

In a recent monographic study, Takahashi [14] has reported 11 Sticta species from the South Asian region including China and Japan. In South Korea, no comprehensive work on Sticta has been done, and very little information is available on most of the known South Korean species. Park [15] has made a key description of only two Sticta species, namely, S. nylanderiana and S. yatabeana. To date, seven species have been reported from South Korea [16]. These include Sticta fuliginosa (Dicks.) Ach., Sticta gracilis (Müll. Arg.) Zahlbr., Sticta limbata (Sm.) Ach., Sticta nylanderiana Zahlbr., Sticta weigelii (Ach.) Vain., Sticta wrightii Tuck., and Sticta yatabeana Müll. Arg. Therefore, our aim in this study was to identify the presence of other Sticta species in the South Korean lichen species collection, which is deposited in the Korean Lichen Research Institute (KoLRI), by using taxonomic, chemical, and molecular analyses.

MATERIALS AND METHODS

The study was based on the specimens deposited in the KoLRI. The lichen samples were identified using stereo and light microscopes: a dissecting microscope (SMZ645; Nikon, Tokyo, Japan) was used for examining the thallus morphology, reproductive structures, color, size, and shape, and a compound microscope (ZEISS Scope, A1; Zeiss, Oberkochen, Germany) was used for studying the anatomy of thalli. Spot test reactions were carried out on thalli under a compound microscope.

Chemicals were extracted in analytical-grade acetone using 0.1 g of the thallus in a 1-mL Eppendorf tube. Then,
thin layer chromatography (TLC) was done using a glass plate coated with TLC Silica gel 60, in solvent system A (toluene : dioxin : acetic acid = 180 : 45 : 5) [17]. All examined localities of specimens were mapped using open source GIS software Quantum GIS 1.7.0 (http://www.qgis.org). Voucher specimens have been deposited in the herbarium of the Lichen & Allied Bio-resource Centre at the KoLRI, Sunchon National University, South Korea.

Total DNA was extracted directly from the thalli of the selected specimens (KoLRi000321-KF730790, KoLRi000449-KF730791, KoLRi000460-KF840681, KoLRi000468-KF730792, and KoLRi008817-KF730793) [18] and was purified using the DNeasy Plant Mini Kit (Qiagen, Hilden, Germany). The nuclear ribosomal RNA gene region, including the internal transcribed spacers (ITSs) 1 and 2 and the 5.8S subunit (ITS), was amplified using the primers ITS1F [19] and LR5 [20]. Amplification was performed on a TaKaRa JP/TP600 PCR machine (TaKaRa Bio Inc., Otsu, Japan). PCR products were then sent to the sequencing facilities of GenoTech Corp. (Seoul, Korea) for cleaning and sequencing.

Alignment was done using BioEdit software [21]. Seventeen additional ITS sequences of Sticta were recovered from GenBank. Ambiguous regions were delimited [22] and excluded from the alignment. Four species—Pseudocyphellaria neglecta (Müll. Arg.) H. Mag., P. crocata (L.) Vain., Lobaria retigera (Bory) Trevis., and Cladonia macilenta Hoffm.—were selected as out-groups on the basis of BLAST comparison in GenBank. Phylogenetic relationships between taxa were investigated using MEGA 5.2 software [23]. The data set was analyzed using the neighbor joining (NJ) method, and support values were obtained using a bootstrap analysis of 1,000 pseudoreplicates.

RESULTS AND DISCUSSION

Phylogenetic analysis. The ITS matrix included 382 characters, 132 of which were variable. The NJ tree (Fig. 1) shows that all S. nylanderiana and S. yatabeana are clustered within the well-supported clade (bootstrap, 84%). All species within this clade do not contain any isidia or cluster within the well-supported clade (bootstrap, 84%). The ITS matrix included 382

Fig. 1. Phylogenetic relationships between species of Sticta for which molecular data are currently available in the public database GenBank. This phylogeny was obtained using the marker internal transcribed spacer and an neighbor joining criterion using software MEGA5. Specimens selected for the current study.

2. Lobes isidiate or soreldiate ......................................................... 3
2a. Lobes without isidia and soredia ............................................ 6
3. Sorediate, polyphyllous ......................................................... S. limbata
3a. Thallus isidiate ................................................................. 4
4. Isidia sorediate, medulla K− ............................................. S. sublimbata
4a. Isidia esorediate ............................................................. 5
5. Thallus monoplyllous, isidia granular to coralloid, medulla K− .............. S. fulginosa
5a. Thallus polyphyllous, isidia cylindrical to coralloid, medulla K+ (yellow) ........................................ S. weigelii
6. Upper surface glabrous, medulla KC+ (rose-red), gyrophoric acid present ........................................ S. nylanderiana
6a. Upper surface hirsute, medulla KC−, gyrophoric acid absent ........................................................... 7
7. Cyphellae rounded, shallowly excavate ............ S. wrightii
7a. Cyphellae irregular, scarcely excavate .......... S. yatabeana

Species description. Sticta nylanderiana Zahlbr., Zahlbruckner’s Cat. Lich. Univ. 3: 356 (1925). Thallus lobate, green to grayish-green, non-stipitate, polyphyllous frond, loosely attached, 5–20 cm wide. Lobes irregularly branching, 0.5 to 1.5 cm wide, rounded to truncate apex, without isidia, soredia, or phyllidia. Upper surface smooth, somewhat glossy, without maculae. Medulla white, 60–200 µm thick, loosely interwoven. Photobiont layer 15~70 µm thick with green algae. Lower surface pale
to dark brown, densely tomentose in the middle, glabrous at the margins. Cyphellae round, shallowly excavate with non-prominent margins. Apothecia somewhat rare, 0.6~3 mm in diameter; disc brown, matt, epruinose; margins entire; proper exciple well-developed, smooth to dentate, without photobiont cells. Ascospores fusiform-ellipsoidal to linear, 40~60 × 4~6 µm, 5~7 septate, colorless. Pycnidia laminal, crowded on thallus margin. Conidia 3.0~5.0 × 1~1.5 µm, bacilliform (Fig. 2A).

**Chemistry:** Cortex K−, C−, KC−, P−; medulla K−, C−, KC+ (rose to red), P−. TLC: gyrophoric acid, congyrophoric acid, pseudocyphellarin A, unknown 1 to 5 (Fig. 3).

**Remarks:** *S. nylanderiana* is characterized by the presence of glabrous, shiny upper surface without soredia, isidia, or lobules, rounded cyphellae without non-prominent margins, and gyrophoric acid in the medulla. This species is similar to *S. yatabeana* in external appearance, but the latter species differs in having small cortical hairs on the upper surface and not having gyrophoric acid in the medulla.

**Selected specimens examined:** Mt. Duta, on bark, 37°25′49.8″ N, 128°58′40.5″ E, elev. 1,377 m, 11 May 2008, J. S. Hur, 080175; Mt. Taebaek, on bark, 37°06′11.4″ N, 128°55′55.8″ E, elev. 1,254 m, 20 Aug 2003, J. S. Hur, 030664; on bark, 37°06′11.4″ N, 128°55′55.8″ E, elev. 1,254 m, 20 Aug 2003, J. S. Hur, 030658.

**Ecology and distribution:** *S. nylanderiana* is a common species on barks at higher elevations around 900 m to 1,700 m in South Korea (Fig. 4). This species was reported for the first time in South Korea by Kim [24]. According to Takahashi [14], this species is more widely distributed in Japan. This species has also been found in other Asian and Southeast Asian countries including Bhutan, China, Nepal, Thailand, and Tibet [10, 14, 25].

**Sticta sublimbata** (J. Steiner) Swinscow & Krog, in Galloway, N. Z. J. Bot. 21: 198 (1983). Thallus lobate, green to bluish-gray, non-stipitate, polyphyllous frond, loosely attached, 5~8 cm wide. Lobes irregularly branching, 0.5 to 1.5 cm wide, rounded apex, with sorediate isidia at the margins. Isidia minute, granular-coralloid, dark gray-brown, soon eroding and becoming sorediate.
Upper surface smooth, shallowly wrinkled, maculate. Medulla white, 20–80 µm thick, loosely interwoven. Photobiont layer 25–60 µm thick with cyanobacteria *Nostoc*. Lower surface dark brown to black, densely tomentose. Cyphellae round, shallowly excavate without prominent margins. Apothecia and pycnidia not seen (Fig. 2E).

**Chemistry:** Cortex K−, C−, KC−, P−; medulla K+ (yellow), C−, KC−, P−. TLC: unknown 1 to 4 (Fig. 3).

**Remarks:** *S. weigelii* is characterized by the presence of a non-stipitate thallus and to submarginal coralloid isidia. Further, the color reaction with KOH is specific in this species. According to Takahashi [14], the well-developed thallus of this species contains coralloid isidia not only at the margins but also on the lamina. This species very closely resembles *S. sublimbata* towing to the presence of marginal coralloid isidia, but the latter species is distinguished by the presence of sorediate isidia and absence of chemicals in the medulla.

**Selected specimens examined:** Mt. Taebaek, on rock, 37°06′16.4″ N, 128°56′31.8″ E, elev. 1,011 m, 20 Aug 2003, J. S. Hur, 030646.

**Ecology and distribution:** This species is somewhat rare in South Korea. Only a single specimen was found on a rock at higher elevation (Fig. 4). This species widely distributed in tropical and southern-temperate regions [5]. In East Asia, this species has been found in Japan [14] and China [10, 25].

*Sticta yatabeana* Müll. Arg., Flora 74: 111 (1891).

Thallus lobate, green to grayish-green, non-stipitate, polyphyllous frond, deeply dissected, loosely attached, 5–7 cm wide. Lobes irregularly branching, 0.5 to 1.5 cm wide, rounded apex, with isidia at the sinuous margins, esorediate, etomentose. Isidia minute, cylindrical to coralloid, dark gray-brown, densely crowded at the margins. Upper surface glabrous, flat to concave, maculate. Medulla white, 80–120 µm thick, densely interwoven. Photobiont layer 60–100 µm thick with cyanobacteria *Nostoc*. Lower surface dark brown to black, densely tomentose. Cyphellae round, deeply excavate with prominent margins. Apothecia and pycnidia not seen (Fig. 2E).

**Chemistry:** Cortex K−, C−, KC−, P−; medulla K+ (yellow), C−, KC−, P−. TLC: unknown 1 to 4 (Fig. 3).

**Remarks:** *S. weigelii* is characterized by the presence of a non-stipitate thallus and to submarginal coralloid isidia. Further, the color reaction with KOH is specific in this species. According to Takahashi [14], the well-developed thallus of this species contains coralloid isidia not only at the margins but also on the lamina. This species very closely resembles *S. sublimbata* towing to the presence of marginal coralloid isidia, but the latter species is distinguished by the presence of sorediate isidia and absence of chemicals in the medulla.

**Selected specimens examined:** Mt. Taebaek, on rock, 37°06′16.4″ N, 128°56′31.8″ E, elev. 1,011 m, 20 Aug 2003, J. S. Hur, 030646.

**Ecology and distribution:** This species is somewhat rare in South Korea. Only a single specimen was found on a rock at higher elevation (Fig. 4). This species widely distributed in tropical and southern-temperate regions [5]. In East Asia, this species has been found in Japan [14] and China [10, 25].

*Sticta yatabeana* Müll. Arg., Flora 74: 111 (1891).

Thallus lobate, green to grayish-green, non-stipitate, polyphyllous frond, deeply dissected, loosely attached, 5–10 cm wide. Lobes irregularly branching, 0.5 to 1.5 cm wide, rounded apex, with isidia at the sinuous margins, esorediate, or phyllidiate. Upper surface smooth, somewhat glossy, maculate, tomentose. Medulla white, 150–200 µm thick, loosely interwoven. Photobiont layer 15–30 µm thick with green algae. Lower surface pale to dark brown, densely tomentose at the center, glabrous at the margins. Cyphellae irregular, scarcely collapsed with non-prominent margins. Apothecia stalked, 0.8–5 mm in diameter; disc brown, matt, epruinose; margins entire; proper exciple well-developed, smooth to dentate, with photobiont cells. Ascospores fusiform-ellipsoidal to linear, 40–100 × 3–4 µm, 3–7 septate, colorless. Pycnidia laminal, crowded on thallus margin. Conidia 2.0–6.0 × 1–1.5 µm, bacilliform (Fig. 2G).

**Chemistry:** Cortex K−, C−, KC−, P−; medulla K−, C−, KC−, P−. TLC: unknown 1 to 3 (Fig. 3).

**Remarks:** *Sticta yatabeana* is characterized by a hirsute upper surface without soredia, isidia, or lobules; irregular cyphellae without non-prominent margins; stalked apothecia with thalloid exciple; and the absence of gyrophoric acid in...
the medulla. This species is similar to *S. nylanderiana* in external appearance, but the latter species differs in having a glabrous upper surface and the presence of gyrophoric acid in the medulla.

**Selected specimens examined:** Mt. Odae, on bark, 37°46′21.6″ N, 128°36′04.9″ E, elev. 1,200 m, 8 May 2004, J. S. Hur, 040504; Mt. Taebaek, on bark, 37°06′23.1″ N, 128°54′37.5″ E, elev. 1,290 m, 9 Apr 2004, J. S. Hur, 040182; Mt. Gariwang, on bark, 37°27′26.1″ N, 128°32′44.6″ E, elev. 1,297 m, 10 May 2008, J. S. Hur, 080096.

**Ecology and distribution:** *S. yatabeana* is a common species on barks at higher elevations of about more than 1,200 m in South Korea (Fig. 4). This species was reported for the first time in South Korea by Park [15]. This species has only been found in Japan [14].

**Species excluded in this study.** According to the literature, lichen species *S. fuliginosa* (Dicks.) Ach., *S. gracilis* (Müll. Arg.) Zahlbr., *S. limbata* (Sm.) Ach., and *Sticta wrightii* Tuck. have previously been reported in South Korea. However, the specimens of those species are untraceable, and therefore, the descriptions are based on the previous literatures.

*Sticta fuliginosa* (Dicks.) Ach., Method. Lich.: 280 (1803). This species is characterized by the presence of umbilicate monophyllous thallus, granular to coralloid isidia on upper surface, and round cyphellae with prominent margins [14]. According to Galloway [27], *S. limbata* (Sm.) Ach. has similar morphology with *S. fuliginosa*, but it differs by the presence of somewhat eroded soralia on margins and upper surface. The presence of this species in South Korea was reported for the first time by Kim [24]. This species has only been found in Japan [14], and Mongolia [30].

*Sticta gracilis* (Müll. Arg.) Zahlbr., Zahlbruckner's Cat. Lich. Univ. 3: 386 (1925). This species is characterized by the presence of a polyphyllous thallus and sorediate isidia [5, 14]. The presence of this species in South Korea was first reported by Park [29]. This species is widely distributed in the Northern Hemisphere, East Africa, South America, Australia, and New Zealand. In the East Asian region, this species has been found in China [10, 25] and Japan [14].

*Sticta wrightii* Tuck., Am. J. Sci. Arts, Ser. 2 28: 204 (1859). According to Takahashi [14], two morphotypes of *S. wrightii* exist. The chloromorph is characterized by the presence of glabrous foliose thallus with green algal photobiont, rounded to irregular cyphellae with non-prominent margins, and the absence of gyrophoric acid in the medulla. The cyanomorph of this species is characterized by the presence of a dendriscocauloid thallus with articulately ridged main branches and terete secondary branches, which are densely covered with tomenta. The presence of this species in South Korea was first reported by Kim [24]. The morphotype concept was not developed during that time, but the reported species would have belonged to the chloromorph type. This species has been found in other Asian countries including China [25], Japan [14], and Mongolia [30].

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