1. Introduction

*Buellia* De Not., typified by *B. disciformis* (Fr.) Mudd is a cosmopolitan lichen genus including a large number of crustose lichen species with green photobiont, black lecideine to biorarine apothecia with blackish disc, dark hypothecia and *Bacidia*-type asci with brown to black, 1- or pluriseptate ascospores [1]. Studies of this group have been conducted since it was firstly described by De Notaris [2], with many species being discovered, several suggestions were also proposed on the homogeneity and the segregation of the buellioid lichens. Scheidegger [3] and Marbach [4] separated 13 genera based on morphological-anatomical characters of mainly corticolous taxa, i.e., ascomata, ascus, spore anatomy, spore wall ornamentation, and conidiophore type. *Buellia* in the strict sense is characterized by *Callispora*-type ascospores, bacilliform or weakly clavate conidia and a hymenium with oil droplets [4–6]. However, many species with pluriseptate spores do not form a monophyletic group and remain to be placed in segregate genera, thus they remain classified in the *Buellia* in the broad sense [1,7–9].

Poelt [10] and Hafellner et al. [11] included the family Buelliacae in the Physciaceae, and *Buellia* has long been treated as a well-studied genus of the Physciaceae by investigators worldwide [1,4,7,8,12–14], however, molecular genetic data indicates that the *Buellia* group is not supported as a monophyletic genus [7,15,16]. Rambold et al. [17] proposed two groups based on the ascus types in Physciaceae, i.e., *Buellia* group with *Bacidia*-type ascus and *Physcia* group with *Lecanora*-type ascus. Wedin et al. [18,19] reconstructed the phylogenetic tree of Caliciaceae and Physciaceae, and showed that these two families formed a well-supported monophyletic group, but prototunicate, mazaedia-forming representatives of Caliciaceae were derived from within Physciaceae, and fell into the “*Buellia*-group” clade, so buellioid lichens actually belong to Caliciaceae rather than the Physciaceae [20].

Many substance classes have been reported for buellioid species, including orcinol depsides, β-orcinol depsidones, xanthones, and anthraquinones [7]. However, some of them (e.g., xanthones and anthraquinones) are difficult to distinguish with routine thin-layer chromatography (TLC); therefore, high-performance liquid chromatography (HPLC) was applied to identify the substances [4,21,22], Kalb and Elix [23] investigated the chemistry of 47 buellioid species and confirmed several type species, which gave a great significance for the following chemical and taxonomic studies of buellioid lichens.

Since the first two species have been reported under the genera *Amandinea* and *Hafellia* by Park [24], now 25 buellioid taxa belonging to the following four genera *Amandinea*, *Buellia*, *Hafellia*, and *Sculptolumina* were described based on morphology, chemistry, and molecular phylogeny.
Sculptolumina have been recorded in South Korea [25–31]. Most of them are saxicolous. During our field trips from 2013 to 2016, several lignicolous and coniferous buellioid specimens were collected. In this study, morphological, chemical, and molecular analyses were conducted to confirm their systematic position.

2. Material and methods

2.1. Material and morphological studies

All the specimens in this study were collected from South Korea and deposited in Sunchon National University, Korean Lichen Research Institute (KoLRI). Specimens morphology, and spot test were examined under a dissecting microscope (Nikon SMZ 745 T, Tokyo, Japan), and the anatomical characters were recorded under Olympus BX 50 microscope (Olympus, Tokyo, Japan) and photos under Carl Zeiss MicroImaging with Axio Cam ERc 5 s imaging system (Carl Zeiss MicroImaging, Göttingen, Germany). All measurements based on the sections from the thalli and apothecia were made in the water or KOH solution (5–10%). The ranges of ascospore dimensions were calculated from 30 to 50 ascospore size measurements of a single apothecium per specimen.

2.2. Chemical studies

Amyloid reactions were tested with Lugol’s reagent (IKI). UV test was performed under the UV Chamber (CE07 21470). Secondary metabolites were studied by spot tests and TLC in solvent A, B, B’, and C as described by Elix [32] and Orange et al. [33].

2.3. High-performance liquid chromatography (HPLC)

Samples preparation. Dried thallus and apothecia (ca. 20–30 mg) were scraped from the substrate with a blade under a dissecting microscope, then transferred into 2 mL tubes for 2 h ultrasonic extraction in acetone twice, and after having dissolved with 300 µL acetone, the solution samples were filtered through 0.4 µm syringe membrane before injection to HPLC. Each species was analyzed with three different specimens and two replicates.

HPLC analysis. HPLC was carried out under a Shimadzu liquid chromatography (Prominance Modular HPLC LC-20A; Shimadzu, Kyoto, Japan). The chromatographic conditions were as follows: column, YMC-Pack ODS-A 150 × 4.6 mm I.D., S-5 µm, 12 nm (YMC Co., Ltd., Kyoto, Japan); solvent system, MeOH: H₂O: Phosphoric acid = 80:20:1; flow rate, 1.0 mL/min; column temperature, 40 °C; detector, SPD-M20A, range 180–700 nm; the retention times and UV-spectra of detected peaks were compared with those of known data [34,35].

2.4. Molecular study and phylogenetic analysis

Total genomic DNA was extracted from freshly collected and frozen herbarium specimens using the NucleoSpin Plant II Kit (Clontech Laboratories, Mountain View, CA) following the manufacturer’s instructions. Primers pairs ITS1F [36] and ITS4 [37] were used to amplify the internal transcribed spacer (ITS) region. Protocols of PCR amplification followed Liu et al. [38]. Sequencing was accomplished by the genomic companies GenoTech (Daedeon, Korea) and Macrogen (Daedeon, Korea).

Newly generated ITS sequences were aligned with related buellioloid lichens species from GenBank (Table 1). All raw sequences were assembled and edited using SeqMan (DNAstar packages) and BioEdit version 7.09 [39], then automatically aligned with MUSCLE version 3.6 [40]. Ambiguous regions were identified and excluded using Gblocks [41].

The ITS matrix was analyzed by Maximum likelihood optimality criterion (ML) and Bayesian Inferences (BI) with Dirinaria applanata and Pyxine sorediata as outgroups. ML inferences were performed using RAXML version 7.2.6 [42] with the GTR model, and supported bootstrap values >70% were estimated from the consensus tree built with 2000 trees obtained from nonparametric bootstrapping pseudoreplicates. GTR + I + G were selected best-fitted substitution models based on the Akaike information criterion using jModelTest version 3.7 [43]. BI analyses were performed with MrBayes version 3.1.2 [44] using four chains and run for 1 million generations. Trees were sampled every 1000th generations. Phylogenetic trees were summarized with the first 25% of tree discarded, then the remaining trees were used to generate a majority-rule consensus tree with posterior probabilities (PP), clades of ≥0.95 were considered as significantly supported.

3. Results

A total of 31 taxa including 51 sequences were aligned into the data set for this study, including 15 new ITS and 36 published sequences of buellioloid lichen from GenBank. A total of 449 unambiguous characters were reserved after Gblocks. The phylogenetic tree (Figure 1) depicted based on the ML analysis with bootstrap value and Bayesian PP. Moreover, The ML and the BI trees
Table 1. Information on ITS sequences used in this study, newly generated parts is in boldface.

| Taxon                        | Accession no. | Collection number | Location                      |
|------------------------------|---------------|-------------------|-------------------------------|
| Amandinea lignicola          | JX878521      |                   | USA, Washington, Kitsap Co., Bainbridge Island |
| A. efflorescens              | AY143409      |                   | Australia, Northern Territory, Darwin |
| A. punctata 1                | MF398994      |                   | South Korea, Jeollanam-do      |
| A. punctata 2                | AF224353      | Nordin5346 (UPS)  | Sweden, Uppsala                |
| A. punctata 3                | HQ650627      |                   | Unknown                        |
| A. trassil 1                 | MF399002      |                   | South Korea, Gyeongsangbuk-do  |
| A. trassil 2                 | MF399003      |                   | South Korea, Gangwon-do        |
| Buellia ocellata 1           | MF399006      |                   | Sweden, Narke, Gotland Island Valen |
| B. ocellata 2                | AY143410      | Hafellner 39069 (GZU) | Italy, Udine                  |
| B. chujana 1                 | KT733597      |                   | South Korea, Jeju-si, Mt. Dondae |
| B. buseongensis 1            | MF398999      |                   | South Korea, Jeollanam-do      |
| B. buseongensis 2            | MF399001      |                   | South Korea, Jeollanam-do      |
| B. disciformis               | AF540946      |                   | Unknown                        |
| B. disciformis 1             | FR991139      |                   | United Kingdom                 |
| B. disciformis 2             | AF540498      | A. Nordin 4429 (UPS) | Sweden, Uppland, Riddersholm |
| B. epigaea                   | AF250785      |                   | Unknown                        |
| B. erubescens               | AF250786      |                   | Unknown                        |
| B. frigida (Supplementary 1) | AF276066      | IML 384687 (CABI Bioscience) | Eastern Antarctica, Princess Elizabeth Land |
| B. halonia 1                 | KT733595      |                   | South Korea, Jeju-si, Mt. Dondae |
| B. halonia 2                 | KT733596      | Y. Joshi & J. -U. So 140768 (KoLRI) | South Korea, Jeju-si, Mt. Dondae |
| B. halonae                  | AY971692      |                   | Japan, Miyazaki Pref., Kushima  |
| B. mamillana 1               | KT733599      |                   | South Korea, Jeju-si, Mt. Dondae |
| B. mamillana 2              | KT733600      | Joseph P. Halda 141100 (KoLRI) | South Korea, Jeju-si, port of Yecho-ri |
| B. mamillana 3              | MF399895      | S. Y. Kondratyuk & L. L. Loko 161370 (KoLRI) | South Korea, Gyeongsangbuk-do |
| B. ocellata                 | AF540502      | A. Nordin 4284 (UPS) | Faroe Islands, Skovoy          |
| B. ocellata 1               | AF250779      |                   | Unknown                        |
| B. ocellata 2               | AF250787      |                   | Unknown                        |
| B. ocellata 3               | AF534454      | J. S. Hur ANT070942 (KoLRI) | Antarctica, King George Island |
| B. stellulata 1             | MF398996      | 120219 (KoLRI)    | South Korea, Jeollanam-do      |
| B. subdisciformis            | AF532323      | 1375 (BCO)        | Spain, Cap de Creus, Catalonia |
| Dermatiscum fallax          | KS12921       | Bruse 4944 (S)    | Unknown                        |
| Dermatiscum thambergii      | AF540507      | H. Sipman 19.908 (B) | South Africa, Transvaal Prov. |
| Dimelaena radiata 1         | KS12923       | Nash III 41396 (S) | Unknown                        |
| Dimelaena radiata 2         | JO160139      | C. Scheidegger 140 (DUKE) | Spain, Almeria, Cabo de Gata |
| Dirinaria applanata         | MF398997      | 120062 (KoLRI)   | South Korea, Jeollanam-do      |
| Pysine sorediata            | AY496683      | J. Chen & G. R. Hu 21941 (HMAS) | Unknown                      |
| Sculptolumina coreana 1     | MF399007      | S. Y. Kondratyuk 150282 (KoLRI) | South Korea, Chungcheongbuk-do |
| S. coreana 2                | MF399008      | S. Y. Kondratyuk, L. Loko & C. H. Park 130766 (KoLRI) | South Korea, Jeollanam-do |
| S. coreana 3                | MF399006      | S. Y. Kondratyuk 150282 (KoLRI) | South Korea, Chungcheongbuk-do |
| S. coreana 4                | MF399004      | S. Y. Kondratyuk 110994 (KoLRI) | South Korea, Jeollanam-do |
| S. coreana 5                | MF399008      | D. Liu 163541    | South Korea, Jeollanam-do      |
| Tetramelas confusus         | DQ201954      | Galloway 0239 (UPS) | New Zealand                    |
| T. geography               | AF540499      | A. Nordin 4429 (UPS) | Sweden, Torne Lapmark, Jukkasjarvi |
| T. insignis                 | DQ198358      | A. Nordin 5664 (UPS) | Sweden                          |
| T. papillatus               | AF250790      |                   | Unknown                        |
| T. phaeophysciae 1          | DQ201951      | A. Nordin 5663 (UPS) | Norway                         |
| T. phaeophysciae 2          | DQ198359      | A. Nordin 4922 (UPS) | Iceland                        |
| T. phaeophysciae 3          | K512939       | A. Nordin 6896 (UPS) | Unknown                        |
| T. pulverulentus            | KS12940       | A. Nordin 6368 (UPS) | Unknown                        |

( Supplementary 1) show different topologies, but accords in the terminal branches.

The phylogenetic tree infers that the genus Buellia is polyphyletic; however, Buellia buseongensis and Sculptolumina coreana each form monophyletic groups with strong support, respectively. B. buseongensis is close to Amandinea efflorescens and A. trassil, while S. coreana clade drops out of Buellia. The relationships in Buellia s. lat. are not still full resolved, B. disciformis; the type species of the genus Buellia forms a single clade (Buellia sensu stricto). Additionally, the genus Tetramelas, characterized by large spore and the presence of 6-O-methylarthen [45], is monophyletic which also agrees with former researches [13,20,46–48], and evidence is also given in this study to separate Tetramelas typified by T. geophila from Buellia.

4. Taxonomic treatment

4.1. Buellia buseongensis D. Liu, S.Y. Kondr. & J.-S. Hur, sp. nov

MycoBank No.: MB 821884

Similar to B. polyspora (Tuck.) Marbach but differs in thallus UV + orange and 16-spored apothecia.

Type: South Korea, Jeollanam-do, Boseong-gun, Boseong-eup, Nokcha-ro 775#, Green Tea Garden, 34°43’2”N, 127°4’46”E, 240–266 m, on Cryptomeria sp., 23 Jul. 2016, D. Liu 163552 (holotype). Accession number: MF399001 (ITS) (Figure 2).

Thallus crustose, granular, continuous, light grey or yellow to light yellow-green, 1–3 (–8 cm) across. Soredia and isidia absent. Margin usually delimitated. Prothallus absent, hypothallus present, grey to
silvery. Cortex and medulla not well developed, medulla ca. 80 μm thick when visible, 1-Photobiont algal cells round, trebouxioid

Apothecia numerous, common, immersed to sessile (0.1–0.2–0.56(–0.6) mm diam., disc black, epruinose, plane to convex or rarely weakly concave, cryptocoleanorin. Prope excipular 20–40 μm thick, hyaline inner zones, and dark brown or blackish out zones, paraplectenchymatous or pseudoplectenchymatous with cell lumina 6–9(–11) × 3–5(–7) μm. Hymenium 60–70(–80) μm thick, hyaline, not

inspersed with oil droplets, amyloid. Ephyhymenium indistinct, usually with abundant spores, K-. Hypothecium to 30–70(–80) μm thick, brownish or olive-blackish. Asci Basidia-type, clavate, 57–62 × 10–16 μm, 16-spored. Paraphyses 1–2 μm wide, simple to sparsely branched, swollen toward the tips, apex forming a brown to black caps (2–)2.5–3(–6.6) μm. Ascospores Buellia-type, 1-septate, ellipsoid, constricted, end attenuated, hyaline when immature, turning olive brownish to deep brownish when mature, usually one cell is wider than the other, outer wall smooth, septum and wall distinctly thickened, non-amyloid (9–)10–13.8(–15) × 4–6(–6.5) μm in water and (9–)10–16(–18) × (4–)4.5–6(–8) μm in K. Pycnidia rare, conidia fusi- form to ellipsoid, 4.3 × 5.0 × 2.5–2.9 μm.

Chemistry: Thallus K– or pale yellow, C–, P–, UV + orange, spot after K then UV + bright yellow; 2,7-dichloro-3-O-methylnorlichexanthone (major), thiophanic acid (major), 2,5,7-trichloro-3-O-methyl norlichexanthone (major), norlichexanthone (minor), gyrophoric acid (minor), 4,5-dichloronorlichexanthone (minor), 4,5-dichloro-3-O-methylnorlichexanthone (minor), 2,7-dichlorolichexanthone (minor) by TLC and HPLC.

Etymology: The epithet refers to the location Boseong-gun, South Korea, where the type specimen was collected.

Habitat: This species always grows on bark of various coniferous trees (Cryptomeria, Metasequoia glyptostroboides, Chamaecyparis obtusa, etc.), together Biatora pseudosambuci, Dirinaria, Fellharena, Fuscidea, Lecanora, Lepraria, and Ochrolechia.

Remarks: Buellia boseongensis is characterized by crustose, light grey or yellow to light yellow-green, granular thallus, without soredia and isidia, numerous apothecia, cryptolecaneorin apothecia, 16-spored asci, and containing UV + orange xanthones.

Buellia boseongensis is similar to Amandinea errata Marbach but differs in having much thicker thallus (ca. 180–200 μm vs. 25–50 μm thick), and lacking a well-developed cortical layer and K– vs. cortical layer K+ reddish. B. boseongensis is most similar to A. melaxanthella (Nyl.) Marbach, they share the same class substance xanthones, but the major compounds of B. boseongensis is 2,7-dichloro-3-O-methylnorlichexanthone, thiophanic acid, and 2,5,7-trichloro-3-O-methylnorlichexanthone rather than arthrothelin and thuringone, in addition, ascospores of B. boseongensis are wider ((9–)10–13.8(–15) × 4–6(–6.5) μm vs. 9–12(13) × 4–5.5 μm), and a hypothallus is present; Buellia boseongensis resembles Amandinea trassii and A. efflorescens, but it can be distinguished by having polyspored asci; Buellia boseongensis resembles B.
polyspora, which was known from North America, and corticolous, but it easily distinguished by its UV+ orange thallus and in having 16-spored asci. Buellia boseongensis can be distinguished from Amandinea punctata (Hoffm.) Coppins & Scheid. in having better developed and much thicker thallus, much larger apothecia, distinctly subconvex to convex apothecium disc, as well as a hyaline true exciple in lateral portion, 16-spored asci, and much narrower ascospores; Buellia boseongensis differs from B. lauricassiae and B. numerosa in UV+ orange; Buellia boseongensis is similar with B. rhizocarpica and B. carballaliana, but the latter two species are 8-spored. The organism grows under the same conditions as Sculptolumina coreana, but differs in having Buellia-type (vs. Mischoblastia-type) ascospores and “polyspored” (i.e., 16-spored asci instead of 8-spored).

Buellia boseongensis was previously misidentified in South Korea and recorded as Amandinea melaxanthella [49,31] and Buellia polyspora [28,50], and all the specimens cited under A. melaxanthella and B. polyspora by them are now referred to B. boseongensis.

Additional specimens examined: Jeollanam-do: Boseong-gun, Boseong-eup, Nokcha-ro 775#, Green Tea Garden, 34°43’2” N, 127°4’46”E, 240–260 m, on Cryptomeria sp., October 31 2016, D. Liu 163526,
163527, 163529, 163530, 163531, 163533, 163534, 163535, 163536, 163537, 163538, 163539, and 163540; Jangheung County, Mt. Cheongwan, 34°32’56.1"N, 126°56’11.1"E, alt. 120 m, on Alnus bark, 07 Oct. 2005, L. Lőkos 050632; Sunchon-si: 34°58’10”00.4”N, 127°28’32.9”E, alt. 115 m, on Alnus bark, October 8 2005, L. Lőkos 050672; Sunchon National University: 34°58’10”00.4”N, 127°28’40”00.3”E, 40 m, on Chamaecyparis obtusa, October 30 2016, D. Liu 163546, 163548, 163549, 163550, and 163551; October 2 2016, S. Y. Kondratyuk 163553; Humanitarian faculty, 34°57’59.3”N, 127°28’44.8”E, 70 m, on bark, October 5 2005, L. Lőkos 050625; 34°58’10.8”N, 127°28’36.7”E, on bark of pine tree, October 4 2011, S. Y. Kondratyuk 110994; along river, on bark of Metasequoia glyptostroboides, October 2 2016, S. Y. Kondratyuk 163344, 163345, 163348, 163349, and 163352. Odong-do Island, along the tourist path, 34°44’37.75”N, 127°45’50.57”E, 25 m, on bark of Camellia japonica, Machilus thunbergii, Pinus thunbergii, Quercus serrata, July 28 2013, S. Y. Kondratyuk, L. Lőkos & C. H. Park 130733; Yeosu-si: Hwayang-myeon, Yongji-ri, Najin elementary school yard, 34°42’30.00”N, 127°36’44.46”E, 15 m, on bark of Cedrus deodara, Cerasus, Pinus densiflora, July 28 2013, S. Y. Kondratyuk, L. Lőkos & C. H. Park 130760; Nam-myeon, Geumoh-do Island, Simjang-ri, Simpo coast,
4.2. Sculptolumina coreana D. Liu, S. Y. Kontr. & J.-S. Hur, sp. nov

MycoBank No.: MB 821888

Similar to Sculptolumina japonica, but differs in having a smooth, continuous K-thallus, a narrower excipulum, thicker ephiphyllum, narrower subhyphalium, and in containing secondary metabolites other than flavo-obscurins and myeloconone.

Type: South Korea, Jeollanam-do, Boseong-gun, Boseong-eup, Nokcha-ro 775#, Green Tea Garden, 34°43′2″N, 127°4′46″E, 240–260 m, on Cryptomeria sp., October 31 2016, D. Liu 163541. Accession number: MF399008 (ITS) (Figure 3).

Thallus crustose, continuous to dispersed, from very thin to somewhat slightly warty or with undulating surface, granular to subsquamulose, not being leprose and farinose, dark grey, or green to dark green. Soredia, isidia, hypothallus, and prothallus leprose and farinose, dark grey, or green to dark grey, very thin to somewhat slightly warty or with undulated margin. Proper exciple conspicuous, epruinose, plane to convex or rarely weakly concave disc; hymenium hyaline, inspersed with numerous oil droplets, Bacidia-type asci with eight Mischoblastia-type spores. Additionally, measurements of ascospore size in water and K differ, being much smaller in water as (15–)17–22(–25) × 9–11(–12) μm vs. in K (21–)24–35(–34) × (12–)13–15(–17) μm (Figure 3(E,G)).

Moon [51] recorded Buellia disculiformis (Nyl.) Zahlbr. from South Korea, but this species was subsequently synonymized with S. japonica [4]. Sculptolumina coreana is similar to S. japonica, but differs in having a smooth, continuous (rather than being leprose-granulose) which is colored grey or grey greenish to dark greenish thallus a thicker epihymenium (20–25 μm vs. 4–8 μm), narrower hypothecium (20–)30–50(–60) μm vs. 80–120 μm thick), in having smooth walled (vs. rugulate) ascospores, as well as in lacking K+ purple orange pigment and soredia (S. japonica is more or less diffusely sorediate in places). Furthermore, flavo-obscurins and myeloconone, the compounds in S. japonica [4,23,52,53] were not detected by TLC and HPLC analysis. Sculptolumina coreana was previously misidentified as S. japonica in South Korea [30,49,54]. Re-examination relevant specimens indicated that all refer to S. coreana.

Sculptolumina coreana is similar to S. serotina (Malme) Marbach in that it has very similar ascospores (15–)17–22(–25) × 9–11(–12) μm vs. (16–)18–22(–27) × (8–)9–12(–14) μm after Marbach [4], but differs in having funnel-shaped cell lumina in ascospores (vs. lumina rounded). Moreover, the latter contains lobaric acid [55].

Sculptolumina coreana is easily distinguished from S. conradiae H. Mayrhofer, Giralt, van den Boom & Elix by the Mischoblastia-type ascospores
and its unique secondary chemistry, while *S. conradiana* has 1–3-septate ascospore similar to the *Conradii*-type ascospores and no secondary metabolites [55].

The genus *Sculptolumina* was originally described by Marbach [4], subsequently Giralt et al. [55] described that long filiform conidia provided an additional diagnostic feature for this genus. Although the type species of *Sculptolumina* has not been sequenced, we believe that the new species should be placed in *Sculptolumina* based on following morphological characteristics: crustose thallus, lecideine apothecia with epruinose discs, the hymenium inspersed with oil droplets, *Mischoblastia*-types ascospores and further filiform conidia. Although *S. coreana* is similar to several *Endothyaina* species, but *Endothyaina* has bacilliform conidia.

Additional specimens examined: Gyeongsangnam-do: Tongyeong-si, Yokgi-myeon, Saryang Island, 34°50'10.6"N, 128°10'47.6"E, 73 m, on *Pinus* sp., March 17 2007, 070015. Incheon Metropolitan City: Ganghwa-gun, Samsan-myeon, Seokmo Island, 37°44.475"N, 126°19.368"E, 16 m, on *Quercus* sp., September 29 2010, X. Y. Wang et al. 100991. Jeju-do: Seogwipo-si, Donnaeko-ro, 34°29.300"N, 127°36'44.46"E, 15 m, on bark of *Cedrus deodara*, *Cerasus*, *Pinus densiflora*, July 28 2013, S. Y. Kondratyuk & L. Lökös et al. 130758, 130762, and 130766; along the road at seacoast, 34°39'5.33"N, 127°34'45.67"E, 8 m, on bark of *Camellia japonica*, *Celtis*, *Quercus variabilis*, *Sorbus amurensis*, July 28 2013, S. Y. Kondratyuk et al. 130784, 130762, and 130766; Odong-do Island, along the tourist path, *Michilus thunbergii*, *Pinus thunbergii*, 34°44'37.75"N, 127°45'50.57"E, 25 m, on bark of *Camellia japonica*, July 28 2013, S. Y. Kondratyuk et al. 130735.

5. Discussion

*Buellia* s. lat. is a heterogeneous and species-rich group where the genetic relationships from molecular phylogeny remain ambiguous and poorly resolved in this study, even though several morphological and phylogenetic investigations have been performed [4,7,19]. However, as a result of this study some segregates matched those in a morphological investigation conducted [4], such as genus *Tetramelas*. Nevertheless, further study should be continued to clarify the natural relationship in *Buellia* s. str. clade, which remains highly polyphyletic. Figure 1.

*Buellia* is a cosmopolitan lichen genus and contains ca. 453 species worldwide, although several segregations were separated [4,12], the taxonomy of *Buellia* s. l. is still controversial. Most of species in this group have 8-spored asci, and less than 20 species have polyspored asci [1,4]. *B. booseongensis* is characterized by 16-spored asci similar with *B. polyspora*, *A. errata*, and *A. melaxanthella*; however, it is unfortunate that we are not available to get the ITS sequences and have a contrast with each other on the basis of DNA information. The phylogenetic tree infers that *B. booseongensis* is far from *A. punctata*, although it is close to *A. trassil* and *A. efflorescens*, the morphological difference among them is easy to be distinguished; moreover, the determination of the genus *Amandinea* need further study.

The genus *Sculptolumina* was separated from *Buellia* by Marbach [4] based on following characteristics: the lecideine apothecia, hymenium inspersed oil droplets, *Mischoblastia*, or *Pachyvaroria* types spores; then Giralt and Clerc
[46] expanded the diagnostic character with a long and often curved filiform conidia based on the re-examination of holotype. Giralt et al. [55] described *S. conradiae* from Guatemala on the basis of spore type, but lacking conidia information; the morphology of new species *S. coreana* matches the genus characters recorded by Marbach and Giralt, and distinctly differs from those of *Buellia*. The phylogenetic tree also shows *S. coreana* forms a separated clade with *Buellia* (typed by *B. disciformis*).

Large numbers of chemical compounds have been recorded in buellioid lichens, like xanthones, which may be used as an important character for species identification. However, it is still difficult to confirm the actual chemistry due to the absent of standard controls, but when combined with the HPLC chemical fingerprint chromatography, the characteristics of unknown compounds like UV spectra can be recorded. Previously, *Sculptolumina* contained three species, all of which differ in either chemistry or spore type. The chemistry of *S. coreana* differs from all three, although it is not clear what compounds it contains.

**Key to the species of buellioid lichen from Korea**

1a. Habitat corticolous (growing on bark) 2
1b. Habitat saxicolous (growing on rock) 8
2a. Hymenium with numerous oil droplets; ascus 8-spored 3
2b. Hymenium without numerous oil droplets; ascus 8- to 16-spored 4
3a. Thallus rimose, white to grey yellow, exiple dipersa-type, ascus Callipora-type  Buella. disciformis
3b. Thallus granular to subsquamulose, green; exiple trachyspora-type, ascospore Mischoblastia-type  S. coreana
4a. Thallus sorediate, rimose to areolate; ascus 8-spored, ascospores subuniform, 8–12 cells  B. griseovirens
4b. Thallus granular to subsquamulose; ascus 8- or more-spored, ascospores 1-septate 5
5a. Ascus 16- or more-spored 6
5b. Ascus 8-spored 7
6a. Thallus aerolate; ascus (24–)32–48-spored pseudomultispora  Amandinea
6b. Thallus continuous; ascus 16-spored 7
7a. Sorediate 8b. Esorediate 8
8a. Thallus C + orange or pink 9
8b. Thallus C– 12
9a. Thallus P + yellow or orange 10
9b. Thallus P– 11
10a. Ascospore (11.5) 12.4–15.7 (19) × (6.68–)8.9(–9) μm  B. halonia
10b. Ascospore (9)10–13 (14) × 5–7 μm  B. chujadoensis
11a. Prothallus usually present, thallus C + pink, ascospore (8.9)1–11.14 (× (4.5)4.9–6.3(7) μm; medulla amyloid (l + blue)  B. cf. uberior
11b. Prothallus absent, thallus C + orange, ascospore (9)10–13 (–14) × 5–7 μm; medulla non-amyloid (l–)  B. ocellata
12a. Thallus UV + orange 13
12b. Thallus UV – 14

(continued)

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**References**

[1] Bungartz F, Nordin A, Grube U. Buellia. In Nash III TH, Gries C, Bungartz F, editors. Lichen flora of the greater Sonoran desert region. Vol 3. Tempe, Arizona: Arizona State University; 2007. p. 113–179.

[2] De Notaris G. Frammenti lichenographici di un lavoro inedito. Parla Gior Bot Ital. 1846;2:174–224.

[3] Scheidegger C. A revision of European saxicolous species of the genus *Buellia* de Not. and formerly included genera. Lichenologist. 1993;25:315–364.

[4] Marbach B. Corticole und lignicole Arten der Flechtengattung *Buellia*-sensu lato in den Subtropen und Tropen. Bibl Lichenol. 2000;7:315–364.

[5] Elix JA. New species and new records of buellioid lichens from islands of the South Pacific Ocean. Telopea. 2016;19:1–10.

[6] Elix JA, Mayrhofer H. New species and new records of buellioid lichens *(Physciaceae,
Ascomycota) from New Zealand. Telopea. 2017;20:75–84.

[7] Nordin A. Taxonomy and phylogeny of Buellia species with plurisepate spores (Lecanorales, Ascomycotina). Acta Univ Ups Symb Bot Ups. 2000;33:1–17.

[8] Trinkaus U, Mayrhofer H, Elix JA. Revision of the Buellia epigea-group (lichenized Ascomycetes, Physciaceae) 2. The species in Australia. Lichenologist. 2001;33:47–62.

[9] Bugnartz FN. New and previously unrecorded saxicolous species of Buellia s.l. with one-septate ascospores from the Greater Sonoran Desert Region. Mycotaxon. 2004;90:81–123.

[10] Poelt J. Classification. The lichens. New York (NY): Academic Press; 1973.

[11] Hafellner J, Mayrhofer H, Poelt J. Die Gattungen der Flechten familie Physciaceae. Herzogia. 1979;5:39–79.

[12] Sheard JW, May PF. A synopsis of the species of Amandinea (lichenized Ascomycetes, Physciaceae) as presently known in North America. Bryologist. 1997;100:159–169.

[13] Nordin A. Buellia species with plurisepate spores: new and unrecorded species in North America. Bryologist. 1999;102:249–264.

[14] Paz-Bermúdez G, Giralt M, Elix JA. Buellia carballalatiana (Physciaceae), a new lignicolous species from Portugal. Bryologist. 2009;112:845–849.

[15] Grube M, Arup U. Molecular and morphological evolution in the Physciaceae (Lecanorales, lichenized Ascomycotina), with special emphasis on the genus Rinodina. Lichenologist. 2001;33:63–72.

[16] Scheidegger C, Mayrhofer H, Moberg R, et al. Evolutionary trends in the Physciaceae. Lichenologist. 2001;33:25–45.

[17] Rambold G, Mayrhofer H, Matzer M. On the ascus types in the Physciaceae (Lecanorales). Pl Syst Evol. 1994;192:31–40.

[18] Wedin M, Döring H, Nordin A, et al. Small sub-unit rDNA phylogeny shows the lichen families Caliciaceae and Physciaceae (Lecanorales, Ascomycotina) to form a monophyletic group. Can J Bot. 2000;78:246–254.

[19] Wedin M, Baloch E, Grube M. Parsimony analyses of mtSSU and nTS rDNA sequences reveal the natural relationships of the lichen families Physciaceae and Caliciaceae. Taxon. 2002;51:655–660.

[20] Prieto M, Wedin M. Phycology, taxonomy and diversification events in the Caliciaceae. Fungal Divers. 2017;82:221–238.

[21] Bungartz F, Elix JA, Nash TH. The genus Buellia sensu lato in the Greater Sonoran desert egin: saxicolous species with one-septate ascospores containing xanthones. Bryologist. 2004;107:459–479.

[22] Obermayer W, Blaha J, Mayrhofer H. Buellia centralis and chemotypes of Dimelaena oreina in Tibet and other Central-Asian regions. Symb Bot Ups. 2004;34:327–342.

[23] Kalb K, Elix J. The chemistry of some species of Buellia sensu lato (Lecanorales, lichenized Ascomycotina). Quimica de algunas especies de Buellia sensu lato (Lecanorales, hongos liquenizados). Mycotaxon. 1998;68:465–482.

[24] Park YS. Lichen of Korea. J Sci Edu. 1982;7:13–29.

[25] Josh Y, Koh YJ, Hur JS. Further additions to lichen genus Buellia De Not. in South Korea. Mycobiology. 2010;38:222–224.

[26] Zhang LL, Wang XY, Zhao ZT, et al. Lichens newly recorded from the South Korean coast. Mycotaxon. 2012;122:421–432.

[27] Kondratyuk SY, Lökkö S, Haldal JP, et al. New and noteworthy lichen-forming and lichenicolous fungi 5. Acta Bot Hung. 2016;58:319–396.

[28] Joshi Y, Wang XY, Lokos L, et al. Notes on Lichen Genus Buellia De Not. (lichenized Ascomycetes) from South Korea. Mycobiology. 2010;38:65–69.

[29] Hur JS, Koh YJ, Harada H. A checklist of Korean lichens. Lichenology. 2005;4:66–95.

[30] Kondratyuk SY, Lökkö S, Farkas E, et al. New and noteworthy lichen-forming and lichenicolous fungi 2. Acta Bot Hung. 2015;57:77–141.

[31] Kondratyuk SY, Lökkö S, Tschabanenko S, et al. New and noteworthy lichen-forming and lichenicolous fungi. Acta Bot Hung. 2013;55:275–349.

[32] Elix JA. A catalogue of standardized chromato- graphic data and biosynthetic relationships for lichen substances. Canberra, Australia: The Author; 2014.

[33] Orange A, James P, White F. Microchemical methods for the identification of lichens. 2nd ed. London: British Lichen Society; 2010.

[34] Yoshimura I, Kinoshita Y, Yamamoto Y, et al. Analysis of secondary metabolites from lichen by high performance liquid chromatography with a photodiode array detector. Phytochem Anal. 1994;5:197–205.

[35] Huneck S, Yoshimura I. Identification of lichen substance. Berlin Heidelberg: Springer; 1996.

[36] Gardes M, Bruns TD. ITS primers with enhanced specificity for basidiomycetes – application to the identification of mycorrhizae and rusts. Mol Ecol. 1993;2:113–118.

[37] White TJ, Bruns T, Lee S, et al. Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. PCR Protocols: a Guide to Methods and Applications. Vol 18. Cambridge (MA): Academic Press; 1990. p. 315–322.

[38] Liu D, Wang XY, Li JW, et al. Contributions to the lichen flora of the Hengduan Mountains, China (6): revisional study of the genus Canoparmelia (lichenized Ascomycota, Parmeliaceae). Plant Divers Resour. 2014;36:781–787.

[39] Hall TA. BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. Nucleic Acids Symp Ser. 1999;41:95–98.

[40] Edgar RC. MUSCLE: multiple sequence alignment with high accuracy and high throughput. Nucleic Acids Res. 2004;32:1792–1797.

[41] Castresana J. Selection of conserved blocks from multiple alignments for their use in phylogenetic analysis. Mol Biol Evol. 2000;17:540–552.

[42] Stamatakis A. RAxML Version 8: a tool for phylo- genetic analysis and post-analysis of large phyloge- nies. Bioinformatics. 2014;30:1312–1313.

[43] Posada D. jModelTest: phylogenetic model averaging. Mol Biol Evol. 2008;25:1253–1256.

[44] Hueschenbeck JP, Ronquist F. MrBayes: bayesian inference of phylogenetic trees. Bioinformatics. 2001;17:754–755.

[45] Kalb K. New or otherwise interesting lichens II. Bibl Lichenol. 2004;88:301–330.
[46] Giralt M, Clerc P. *Tetramelas thiopolizus* comb. nov. with a key to all known species of *Tetramelas*. Lichenologist. 2011;43:417–425.

[47] Nordin A, Tibell L. Additional species in *Tetramelas*. Lichenologist. 2005;37:491–498.

[48] Nordin A. New species in *Tetramelas*. Lichenologist. 2004;36:355–359.

[49] Kondratyuk SY, Lőkös L, Halda JP, et al. New and noteworthy lichen-forming and lichenicolous fungi 4. Acta Bot Hung. 2016;58:75–136.

[50] Wang XY, Liu D, Lőkös L, et al. New species and new records of *Buellia* (lichenized Ascomycetes) from Jeju Province, South Korea. Mycobiology. 2016;44:14–20.

[51] Moon KH. Mt. Pukhan National Park Forest ecosystem impact assessment and measures for the establishment of urban pollution-lichens. Seoul: Korea National Park Service; 1998. p. 115–126.

[52] Elix JA. *Sculptolumina*, Australian *Physciaceae* (lichenised Ascomycota). 2011. http://www.anbg.gov.au/abrs/lichenlist/Sculptolumina.pdf.

[53] Büdel B, Elix JA. *Peltula langei* Buedel et Elix spec. nov. from Australia, with remarks on its chemistry and the ascoma of *Peltula clavata* (Krempelh.) Wetm. Bibl Lichenol. 1997;67:3–9.

[54] Joshi Y, Lokos L, Wang X, et al. Identification of *Sculptolumina japonica* (*Physciaceae*) in South Korea. Mycobiology. 2010;38:62–64.

[55] Giralt M, Boom P, Mayrhofer H, et al. Three new species of crustose *Physciaceae* from Guatemala, with notes on some additional species. Phytotaxa. 2014;164:79–90.