

## *Arthonia dokdoensis* and *Rufoplaca toktoana* – Two New Taxa from Dokdo Islands (South Korea)

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### ABSTRACT

*Arthonia dokdoensis* sp. nov., a lichenicolous fungus from the subcosmopolitan *Arthonia molendoi* complex growing on crustose thalli of species of the genus *Orientophila* (subfamily Xanthorioideae, Teloschistaceae), as well as the lichen species *Rufoplaca toktoana* sp. nov. (subfamily Caloplacoideae, Teloschistaceae) similar to *Rufoplaca kaernefeltiana*, both from Dokdo Islands, Republic of Korea, are described, illustrated, and compared with closely related taxa. In the phylogenetic tree of the *Arthoniaceae* based on 12S *mtSSU* and *RPB2* gene sequences, the phylogenetic position of the *A. dokdoensis* and the relationship with the *A. molendoi* group are illustrated, while the position of the newly described *R. toktoana* is confirmed by phylogenetic tree based on ITS nrDNA data.

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## 1. Introduction

During a recent investigation of lichen-forming and lichenicolous\* fungi (\*lichenicolous, i.e., growing or inhabiting on lichen thalli [or thalli of lichen-forming fungi]) of Dokdo Islands, two members of the genera *Arthonia* (Ach.) (*Arthoniaceae*) and *Rufoplaca* Arup, Søchting & Frödén (subfamily Caloplacoideae of the Teloschistaceae) were newly found.

Within our study from combined phylogenetic analysis of the *Arthoniaceae* based on *mtSSU* and *RPB2* sequences, the *Arthonia molendoi* group was positioned in the monophyletic branch. Several arthonioid species were already known to grow on foliose or fruticose members of the Teloschistaceae, namely *Arthonia sytnikii* S. Y. Kondr., *Arthonia anjutae* S. Y. Kondr. et Alstrup and *Arthonia descruens* var. *nana* Grube et Hafellner, as well as *A. molendoi* (Heufl. ex Frauenf.) R. Sant. All of them infect the thallus, and some of them also develop fruiting bodies on the apothecia (hymenia) of their hosts. Selected characters of taxa mentioned above have been recently summarized by Fleischhacker et al. [1], who described a new taxon, *Arthonia parietinaria* Hafellner et A. Fleischhacker, a member of the *A. molendoi* group, and compared with *Arthonia anjutae*, *A. sytnikii*, as well as *Arthonia epiphyscia*,

and *A. molendoi*. It was concluded that the status of taxa mentioned at the species level had been confirmed by the taxonomic position of hosts in separate genera of the *Teloschistaceae*, which recently have been proved by three-gene phylogeny (see [2]). Thus *A. parietinaria* has hosts of the genus *Xanthoria* Th. Fr. (as it is correctly stressed by Fleischhacker et al. [1]), while lichenicolous fungi previously recorded on *Massjukiella polycarpa* (Hoffm.) S.Y. Kondr., Fedorenko, S. Stenroos, Kärnefelt, Elix, Hur & A. Thell and/or *Oxneria huculica* S.Y. Kondr. are highly likely to belong to different taxa. *A. anjutae* was confirmed as a species of the genus *Teloschistes* Norm. (the subfamily Teloschistoideae of the Teloschistaceae), *A.* as a species of the genus *Jackelixia* S. Y. Kondr., Fedorenko, S. Stenroos, Kärnefelt & A. Thell, and *A. molendoi* as a species of the genus *Rusavskia* S. Y. Kondr. & Kärnefelt (both latter genera, i.e., *Jackelixia* and *Rusavskia* of the subfamily Xanthorioideae of the Teloschistaceae). The further taxon from the *A. molendoi* complex, which was confirmed as a species of the genus *Orientophila* Arup, Søchting & Frödén (subfamily Xanthorioideae, Teloschistaceae), is segregated in this article.

The genus *Rufoplaca* Arup, Søchting & Frödén (subfamily Caloplacoideae, Teloschistaceae) was introduced in 2013 for six species and two

additional species have subsequently been described [3–5]. Additionally, to eight species of the genus *Rufoplaca*, hitherto known from various regions of the Northern Hemisphere, was added one new species found among Dokdo lichens.

The aim of this article was to present legal descriptions of these two taxa of the genera *Arthonia* and *Rufoplaca*.

## 2. Materials and methods

### 2.1. Taxon sampling

More than 230 lichen specimens were collected in 17 localities of Dokdo Islands, the Republic of Korea in September 2017. The Dokdo specimens, as well as previous collections included in comparative studies and kept in the KoLRI and other herbaria (BP, KW-L, LE, LWG, and VBI), were examined using standard microscopic techniques and hand-sectioned under a dissecting microscope (Nikon SMZ 645; Nikon, Tokyo, Japan). Anatomical descriptions were based on observations of these preparations under a microscope (Nikon Eclipse E200; Nikon, Tokyo, Japan, and Zeiss Scope, A1; Carl Zeiss, Oberkochen, Germany) with digital camera AxioCam ERc 5s. A section of apothecia was tested with water and with potassium (K) and iodine-potassium iodide (IKI) (10% aqueous potassium iodide) for identification [4,5]. Well-preserved and freshly collected lichen specimens lacking any visible symptoms of fungal infection were selected for DNA isolation. Although not possible for all taxa, an attempt was made to achieve a sample series with at least two specimens of each newly sequenced species, preferably from different localities, to ensure species determination by avoiding contamination through unintentional sampling of a wrong individual or sequencing errors.

A total of 11 new sequences (6 nrITS, 2 mtSSU, and 3 RPB2 sequences) from 8 specimens belonging to 3 species in Dokdo and Ulleung-do islands (Table 1), as well as approximately 150 sequences from GenBank (27 ITS nr DNA, 71 mtSSU, and 78 RPB2), were used for phylogenetic analysis.

### 2.2. Molecular data

Genomic DNA was isolated from lichen specimens using the CTAB extraction protocol [21]. For some tiny crustose species (e.g., *Arthonia* or *Rufoplaca*), contaminations with co-occurring fungi are frequent when using standard DNA isolation protocols on large parts of the lichen thalli. To avoid such contamination, hand-made sections of the hymenium or the thallus were used for direct polymerase chain reaction (PCR) [22]. Any pigmented or crystal-

encrusted portions were removed with a razor blade. In addition, the lichen material was sometimes washed with acetone or a 1% KOH solution, and then rinsed with water to remove remnants of pigments.

The material was then added to a tube containing the PCR reaction mixture and amplified directly. Amplification reactions were prepared for a 50  $\mu$ L final volume containing 5  $\mu$ L 10 $\times$  DreamTaq Buffer (Fermentas, Waltham, MA), 1.25  $\mu$ L of each of the 20  $\mu$ M primers, 5  $\mu$ L of 2.5 mg mL<sup>-1</sup> bovine serum albumin (Fermentas #B14), 4 mL of each of the 2.5 mM dNTPs (Fermentas), 1.25 U DreamTaq DNA polymerase (Fermentas) and 1  $\mu$ L of template genomic DNA or tiny fragments of lichen material.

The nuclear ribosomal RNA gene region including the internal transcribed spacers 1 and 2 and the 5.8S subunit (ITS) was amplified using the primers ITS1F [23] and ITS4 [24], the 28S LSU using the primer LR5 [25], and the 12S mtSSU using the primers mtSSU1-mtSSU3R and mtSSU2R [14,20]. Methods of DNA extractions, data on primers, and phylogenetic analysis are provided in our previous article [26].

A fragment of about 1 kb of the RPB2 protein-coding gene was amplified using primers fRPB2-7cF and fRPB2-11aR [27]. The yield of the PCRs was verified by running the products on a 1% agarose gel using ethidium bromide. The amplicons were sequenced by Macrogen<sup>®</sup> using the amplification primers. Two additional primers, RPB2-2488F and RPB2-2492R [28], were used for sequencing RPB2. See also Park et al. [29] and Kondratyuk et al. [26] for extractions, amplifications, and sequencing procedures.

Sequence fragments were assembled with Sequencher version 4.6 (Gene Codes Corporation, Ann Arbor, MI). Sequences were subjected to MEGABLAST searches to verify their closest relatives and to detect potential contaminations.

### 2.3. Phylogenetic analyses

The NucITS, mtSSU, and RPB2 sequences for taxa listed in Table 1 were aligned manually using MacClade version 4.05 (Sunderland, MA) [30].

A conflict was assumed to be significant if two different relationships (one being monophyletic and the other being non-monophyletic) for the same set of taxa were both supported with bootstrap values  $\geq 70\%$  [31].

The mtSSU and RPB2 datasets were concatenated. The combined two-locus dataset consisted of 180 terminals and 1777 unambiguously aligned sites: 856 for the mtSSU and 921 for RPB2. Bayesian inference, maximum likelihood, and parsimony were

**Table 1.** Species of the *Arthoniaceae* and the *Caloplacoideae* of the *Teloschistaceae* included in the phylogenetic analyses and the GenBank accession numbers of the sequences. New sequences generated are indicated in bold.

Species name	Voucher specimen/reference	ITS	12S mt SSU	RPB2
1. <i>Alyxoria ochrocheila</i>	Ertz et al. [6]		EU704073	EU704035
2. <i>Alyxoria ochrocheila</i>	Ertz et al. [6]		EU704072	EU704037
3. <i>Alyxoria ochrocheila</i>	Ertz et al. [6]		EU704071	
4. <i>Alyxoria varia</i>	Frisch et al. [7]		KJ851006	KJ851147
5. <i>Alyxoria varia</i>	Frisch et al. [7]		KF707642	KF707664
6. <i>Alyxoria varia</i>	Miadlikowska (unpubl.)		KT232221	
7. <i>Alyxoria varia</i>	Ertz et al. [6]		EU704075	EU704039
8. <i>Alyxoria varia</i>	Schoch et al. [8]		FJ772243	
9. <i>Arthonia apatetica</i>	Frisch et al. [7]		KJ850994	KJ851126
10. <i>Arthonia apotheciorum</i>	Frisch et al. [7]		KJ850970	KJ851148
11. <i>Arthonia biatoricola</i>	Frisch et al. [7]		KJ850990	KJ851149
12. <i>Arthonia calcarea</i>	Ertz et al. [6]		EU704065	EU704028
13. <i>Arthonia calcarea</i>	Ertz et al. [6]			EU704029
14. <i>Arthonia calcarea</i>	Frisch et al. [7]		KJ850974	
15. <i>Arthonia didyma</i>	Ertz et al. [6]		EU704047	
16. <i>Arthonia didyma</i>	Frisch et al. [7]		KJ851106	
17. <i>Arthonia dokdoensis</i>	SK L06, South Korea, Dokdo Islands, 07.09.2017 J. J.Woo 171029 (KoLRI 045310)	171029	171029	171029
18. <i>Arthonia dokdoensis</i>	SK L05, South Korea, Dokdo Islands, 07.09.2017 J. J.Woo 171032 (KoLRI 045313)			171032
19. <i>Arthonia dokdoensis</i>	SK L04, South Korea, Dokdo Islands, 07.09.2017 J. J.Woo 171034 (KoLRI 045315)		171034	171034
20. <i>Arthonia granitophila</i>	Frisch et al. [7]		KJ850981	KJ851107
21. <i>Arthonia incarnata</i>	Frisch et al. [9]		KY983975	KY983983
22. <i>Arthonia incarnata</i>	Frisch et al. [9]		KY983976	KY983984
23. <i>Arthonia lapidicola</i>	Frisch et al. [7]		KJ850997	KJ851119
24. <i>Arthonia lobariellae</i>	Frisch et al. [7] as <i>Arthonia</i> sp. " <i>lobariicola</i> "		KJ851001	KJ851127
25. <i>Arthonia lobariellae</i>	Frisch et al. [7] as <i>Arthonia</i> sp. " <i>lobariicola</i> "		KJ851002	KJ851128
26. <i>Arthonia molendoi</i>	Frisch et al. [7]		KJ851000	KJ851117
27. <i>Arthonia neglectula</i>	Frisch et al. [7]		KJ850989	KJ851118
28. <i>Arthonia peltigerina</i>	Frisch et al. [7]		KJ850998	KJ851122
29. <i>Arthonia phaeophysciae</i>	Frisch et al. [7]			KJ851112
30. <i>Arthonia physcidiicola</i>	Frisch et al. [7]		KF707646	KF707657
31. <i>Arthonia radiata</i>	Ertz and Tehler [10]			HQ454651
32. <i>Arthonia radiata</i>	Tehler and Irestedt [11]			EF081373
33. <i>Arthonia radiata</i>	Ertz et al. [6]		EU704048	EU704011
34. <i>Arthonia radiata</i>	Frisch et al. [7]			KJ851109
35. <i>Arthonia stereocaulina</i>	Frisch et al. [7]		KJ850999	
36. <i>Arthonia subfuscicola</i>	Frisch et al. [7]		KJ850971	KJ851111
37. <i>Arthonia subfuscicola</i>	Frisch et al. [7]		KJ850972	
38. <i>Brigantiaea ferruginea</i>	SK 780; Kondratyuk et al. [12]	KF264623	KF264685	
39. <i>Brigantiaea ferruginea</i>	SK 779; Kondratyuk et al. [12]	KF264622	KF264684	
40. <i>Bryostigma muscigenum</i>	Frisch et al. [7]		KJ850991	KJ851124
41. <i>Caloplaca areolata</i>	SK 714; Kondratyuk et al. [13]			
42. <i>Caloplaca cerina</i>	FNM 185; Fedorenko et al. [14]	EU681284	EU680863	
43. <i>Caloplaca stillicidiorum</i>	Gaya et al. [15]	KT291510		KT291649
44. <i>Oxneria huculica</i>	FNM 199; Fedorenko et al. [14]		EU680931	
45. <i>Oxneria huculica</i>	Gaya et al. [16]	JQ301687		JQ301776
46. <i>Oxneria ulophyllodes</i>	FNM 198; Fedorenko et al. [14]	EU691342	EU680930	
47. <i>Oxneria ulophyllodes</i>	Gaya et al. [16]			JQ301779
48. <i>Rufoplaca arenaria</i>	Arup et al. [3]	KC179455		
49. <i>Rufoplaca arenaria</i>	Halicí et al. [17]	KF007908		
50. <i>Rufoplaca arenaria</i>	Vondrák and Malicek [18]	KT934385		
51. <i>Rufoplaca kaernefeltiana</i>	South Korea, Ulleung-do Island, Dodong Port, 11.07.2016 Kondratyuk S. Y. & L. Lőkös 162024 (KoLRI 040262)	162024		
52. <i>Rufoplaca kaernefeltiana</i>	South Korea, Ulleung-do Island, Dodong Port, 11.07.2016 Kondratyuk	162044		

(continued)

Table 1. Continued.

Species name	Voucher specimen/reference	ITS	12S mt SSU	RPB2
	S. Y. & L. Lökös 162044 (KoLRI 040282)			
53. <i>Rufoplaca oxfordensis</i>	Arup et al. [3]	KC179456		
54. <i>Rufoplaca scotoplaca</i>	Gaya et al. [16]	JQ301618	JQ301497	JQ301756
55. <i>Rufoplaca scotoplaca</i>	Arup et al. [3]	KC179457	KC179573	
56. <i>Rufoplaca</i> sp. 43	Arup et al. [3]	KC170458	KC179574	
57. <i>Rufoplaca</i> sp. JV 14429	JV 14429, Vondrák et al. [19]	KU926986		
58. <i>Rufoplaca</i> sp. JV 18681	Vondrák et al. (unpubl.)	MG954203		
59. <i>Rufoplaca</i> sp. D 17245	Vondrák et al. (unpubl.)	MG954209		
60. <i>Rufoplaca subpallida</i>	Arup et al. [3]	KC179459		
61. <i>Rufoplaca toktoana</i>	SK L03, South Korea, Dokdo Islands, 07.09.2017 J.-J.Woo 171044 (KoLRI 045325)	SK L03		
62. <i>Rufoplaca toktoana</i>	SK L07, South Korea, Dokdo Islands, 07.09.2017 J.-J.Woo 171045 (KoLRI 045326)	SK L07		
63. <i>Rufoplaca toktoana</i>	SK L08, South Korea, Dokdo Islands, 07.09.2017 J.-J.Woo 171045 (KoLRI 045326)	SK L08		
64. <i>Rufoplaca toktoana</i>	162040, South Korea, Ulleung-do Island, Dodong Port, 11.07.2016 Kondratyuk S. Y. & L. Lökös 162040 (KoLRI 040278)	162040		
65. <i>Rufoplaca tristiuscula</i>	Arup et al. [3]	KC179460	KC179575	
66. <i>Xanthoria coomae</i>	Arup et al. [3]	NR_120253		
67. <i>Xanthoria mediterranea</i>	Fedorenko et al. [14]	EU681297		
68. <i>Xanthoria monofoliola</i>	SK 3191, Fedorenko et al. [20]	JN984136		
69. <i>Xanthoria parietina</i>	FNM 177; Fedorenko et al. [14]	EU681297		

used to estimate the phylogeny of *Arthoniaceae* based on a concatenated sequence matrix of the two loci. For the Bayesian and the maximum likelihood analyses, the best fit model for the two loci, as well as for the codon positions in the *RPB2* gene, were calculated by applying the Akaike Information Criterion [32] and the program MrModeltest version 2.2 (Uppsala, Sweden) [33] in conjunction with PAUP\* [34]. The prior selection of substitution models supported the GTR + I +  $\Gamma$  model for both the two individual loci, as well as for each codon position in *RPB2*. In the Bayesian analysis, the dataset was analyzed in four partitions, mtSSU and by codon positions for *RPB2*. Posterior probabilities of trees and parameters in the substitution models were approximated with MCMC and Metropolis coupling using the program MrBayes version 3.2.1 (Uppsala, Sweden) [35]. In parsimony analysis, the concatenated dataset was analyzed using the same settings as those used for testing the topological incongruence. The phylogenetic tree of the *Arthoniaceae* obtained from parsimony analysis based on the concatenated mtSSU and *RPB2* sequences as the most illustrative one was included in the article (Figure 1).

Three outgroup species *Oxneria ulophyllodes*, *Oxneria Alfredii*, and *O. huculica* were chosen for

the *Arthoniaceae* tree, but *Brigantiaea ferruginea* for the *Rufoplaca* phylogenetic tree. These taxa were used as the rooting taxa in all the analyses. In total, the dataset for the multilocus phylogenetic tree included 141 sequences and ca. Hundred specimens representing approximately 70 species, while the final tree presented in this article included 38 specimens representing 23 species.

### 3. Results and discussion

#### 3.1. New taxa

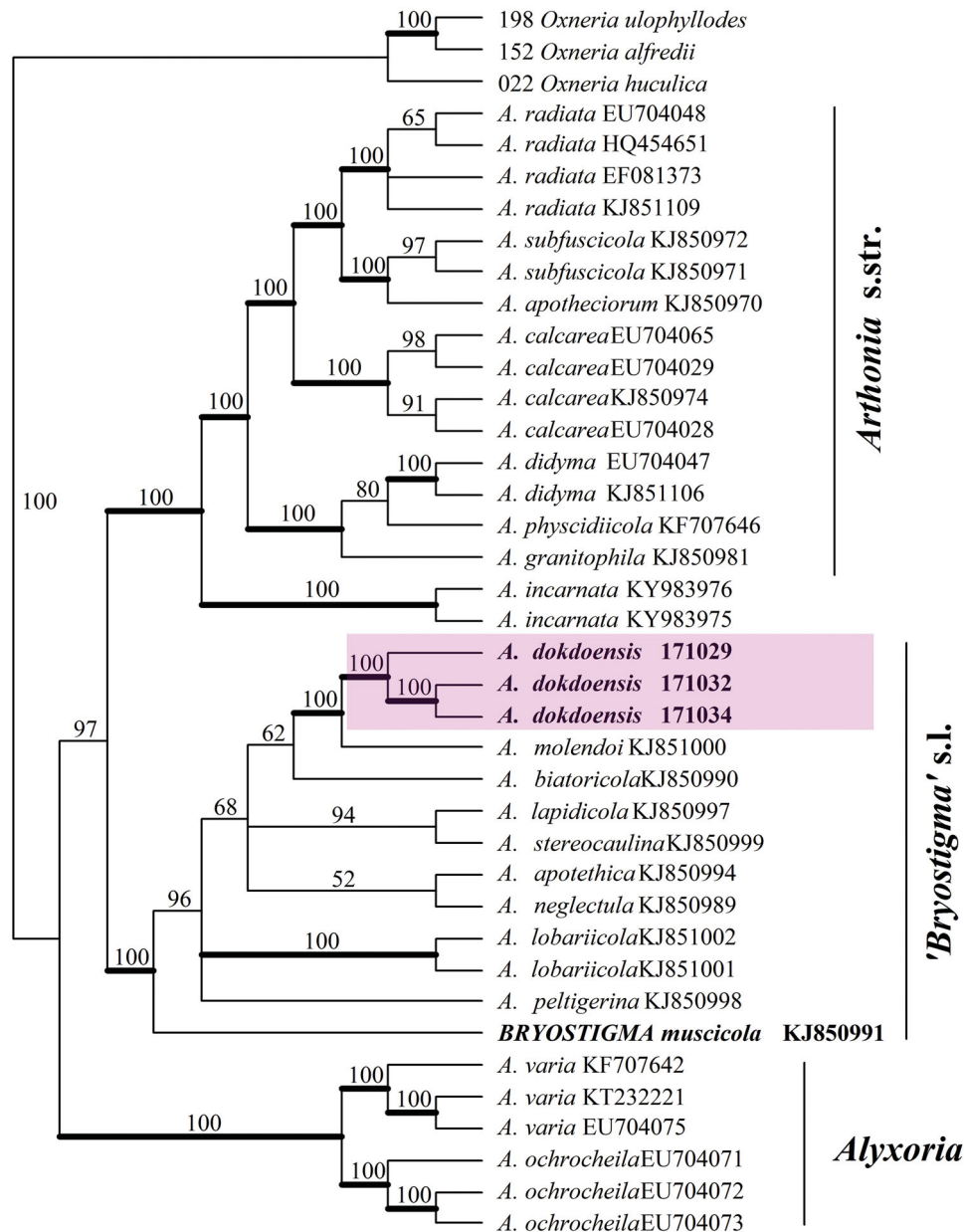
*Arthonia dokdoensis* S. Y. Kondr., L. Lökös, B. G. Lee, J.-J. Woo et J.-S. Hur, sp. nov. (Figure 2)

Mycobank No.: MB 831133.

This species is similar to *A. parietinaria* but differs in causing much smaller infection spots, and in having smaller ascomata, a lower mean number of ascomata per infection spot, more common conidiomata, and bacilliform conidia.

**Type:** Republic of Korea, Gyeongsangbuk-do, Ulleung-gun, Dokdo-ri, Seodo (= Western) Island, on rocks, growing on thalli of *Orientophila yokjidoensis*, growing together with *Polyozosia* aff. *dispersa* and *Orientophila dodongensis*. Lat.: 37° 14' 27" N, Long.: 131° 51' 54" E, Alt.: 100 m a.s.l.



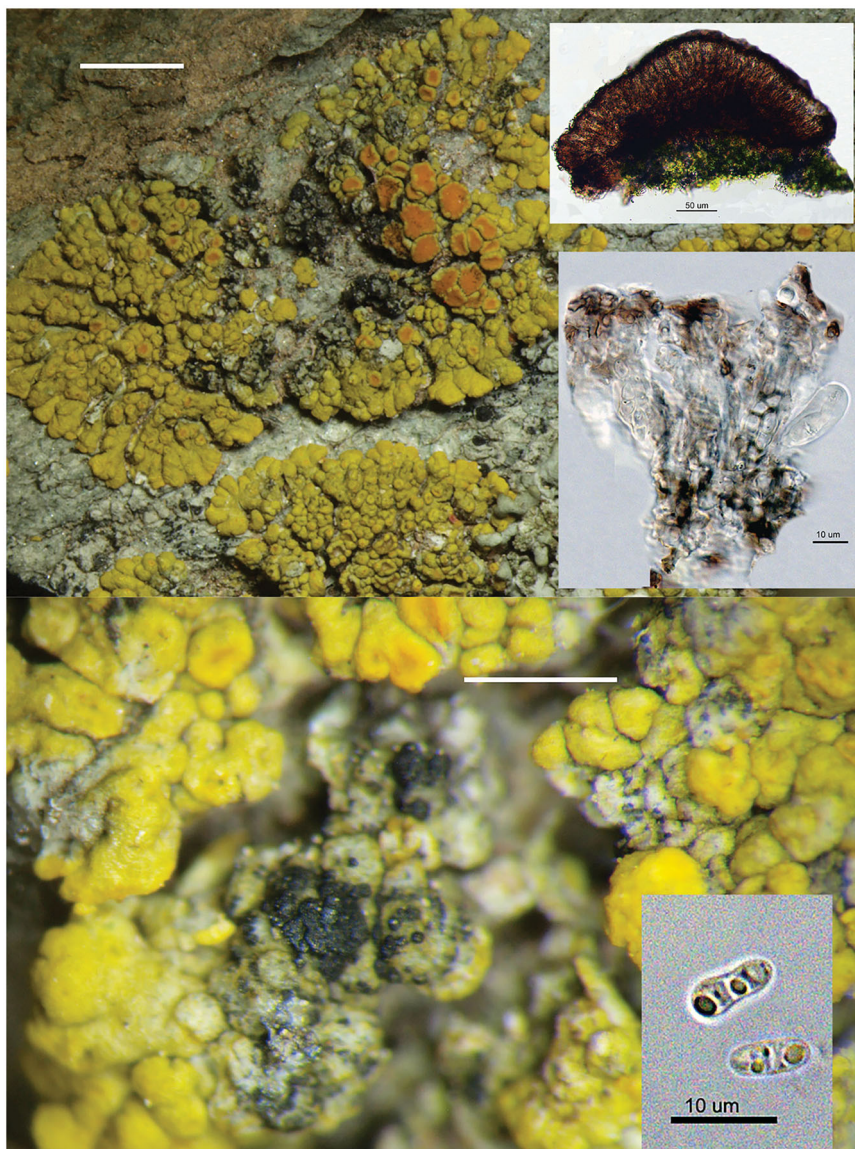


**Figure 1.** Position of the newly described *Arthonia dokdoensis* in the phylogenetic tree of the Arthoniaceae obtained from parsimony analysis based on concatenated mtSSU and RPB2 sequences.

Coll.: Woo, J. J. (171028), 07.09.2017 (KoLRI 045309 sub *Polyozosia* – holotype); the same locality, growing on thalli of *O. yokjidoensis*, growing together with *Physciella* aff. *melanchra* and *Lecanora* sp. Coll.: Woo, J. J. (171029), 07.09.2017 (KoLRI 045310 sub *O. yokjidoensis* – holotype); the same locality, growing on thalli of *O. yokjidoensis*, growing together with *Polyozosia* aff. *dispersa*. Coll.: Woo, J. J. (171030), 08.09.2017 (KoLRI 045311 sub *Polyozosia* – isotype); the same locality, growing on thalli of *O. yokjidoensis*, growing together with *Polyozosia* aff. *dispersa*, *Physciella* aff. *melanchra* and *Diplotomma alboatra*. Coll.: Woo, J. J. (171032), 08.09.2017 (KoLRI 045313 sub *Polyozosia* – isotype); the same locality, growing on thalli of *O. yokjidoensis*, growing together with *Polyozosia* aff. *dispersa*, *Physciella* aff. *melanchra*,

*Buellia ulleungdoensis* and *Lecanora* sp. Coll.: Woo, J. J. (171034), 08.09.2017 (KoLRI 045315 sub *Polyozosia* – isotype); the same locality, growing on thalli of *O. yokjidoensis*, growing together with *Polyozosia* aff. *dispersa*, *Physciella* aff. *melanchra*, *Diploicia canescens*, and *B. ulleungdoensis*. Coll.: Woo, J. J. (171036), 08.09.2017 (KoLRI 045317 sub *D. canescens* – isotype).

**Morphology:** Lichenicolous fungus forming very indistinct infection spots (from very indistinct to more or less recognizable to 0.5–1 mm across) in the central areolate portion of lobate lichen *O. yokjidoensis*, where the peripheral zone of host thalli to 1.5–2.5 mm wide with radially orientated lobes usually not damaged; infection spots often include very small, punctiform, scattered, and distant ascomata or conidiomata.



**Figure 2.** *Arthonia dokdoensis* (holotype), general habit. Scale 2 mm (top, with enlarged section of apothecium, scale 50 µm and enlarged portion of hymenium, scale 10 µm) and 500 µm (bottom, with enlarged ascospores, scale 10 µm).

Ascomata (0.08–)0.1–0.13(–0.14) mm wide, single, round and more or less regular, scattered and distant, and rather inconspicuous, or aggregated in very irregular shape aggregations with 5–10 apothecia together in spots to 0.4–0.6 mm diam./across, often covering one side/portion of the host thalline areole, and better seen. In section, epihymenium olivaceous brown to blackish brown, 4.6–8 µm thick; hymenium 32–40 µm high, in the middle and lower portions more or less hyaline; interscal hyphae branched and anastomosing ca. 2 µm wide; subhymenium (48–)56–64(–80) µm thick, hyaline or light brown; asci clavate, 8-spored; ascospores hyaline (0–)1-septate; lower cell slightly attenuated, 9.6–12.8 × 4–4.8 µm (42 measurements).

Conidiomata very often observed below ascomata and probably especially numerous at first stages of infection development; conidia bacilli-form, 3–4 × 0.8 µm.

Ascomatal gel I + red; KI + blue; asci with KI + blue ring-structure.

**Ecology:** The species grows in the crustose central portion of thalli of lobate lichens *O. yokjidoensis* and *O. dodongensis* growing on siliceous rock.

**Etymology:** It is named after the type locality, namely Dokdo Islands, Republic of Korea, Eastern Asia.

**Distribution:** It is so far known only from the type collection in Dokdo Islands, Republic of Korea, Eastern Asia, where it is rather abundant.

**Taxonomic notes:** The lichenicolous fungus *A. dokdoensis* usually damages the central portion to 0.5–1 mm across, while it hosts thalli to 7–8 mm across with peripheral zone to 1.5–2.5 mm wide with radially orientated lobes, which are usually not damaged by lichenicolous fungi.

Very small ascomata (ca. 80–120 µm in diam. at first) are rather scattered and distant, and are very

barely noticeable. Lichenicolous fungus is usually better distinguished when aggregated ascomata form irregular, often confluent aggregations to 0.4–0.5 mm wide. At this stage, ascomata of lichenicolous fungus often entirely cover the areoles of the central portion of host thalli. The *A. dokdoensis* infection on thalli of *O. yokjidoensis* can be most easy to be recognized at the latest stage.

Sometimes numerous brown hyphae with rounded cells to 4–4.8  $\mu\text{m}$  wide are also observed in host thalli damaged by *A. dokdoensis*. On the other hand, they probably belong to another lichenicolous fungus.

**Additional specimens examined:** Republic of Korea, Gyeongsangbuk-do, Ulleung-gun, Dokdo-ri, Seodo (= Western) Island, on rock, growing on thalli of *O. yokjidoensis* growing together with *Buellia halonia*, and *Lecanora* sp. Lat.: 37° 14' 29.04" N, Long.: 131° 51' 51.4" E, Alt.: 20–25 m a.s.l. Coll.: Park, J. S. (170860), 07.09.2017 (KoLRI 045141 sub *B. halonia*); Dongdo Island, on rock, growing on thalli of *O. yokjidoensis*, growing together with *O. dodongensis*, *Polyozosia* aff. *Dispersa*, and *Physciella* aff. *melanchra*. Lat.: 37° 14' 21.61" N, Long.: 131° 52' 5.71" E, Alt.: 12 m a.s.l. Coll.: Oh, S. O. (171086), 08.09.2017 (KoLRI 045367 sub *Polyozosia* aff. *dispersa*); Seodo Island, near the top level of the trail, on rock, growing on thalli of *O. yokjidoensis* growing together with *Myriolecis* aff. *dispersa*, *B. ulleungdoensis* and *Physciella* aff. *melanchra*. Lat.: 37° 14' 30.02" N, Long.: 131° 51' 50.44" E, Alt.: 25 m a.s.l. Coll.: Lee, B. G. (170928), 07.09.2017 (KoLRI 045209 sub *O. yokjidoensis*); Seodo Island, on rocks, growing on thalli of *O. yokjidoensis*, growing together with *Rufoplaca toktoana*. Lat.: 37° 14' 27" N, Long.: 131° 51' 54" E, Alt.: 100 m a.s.l. Coll.: Woo, J. J. (171044), 07.09.2017 (KoLRI 045325 sub *R. toktoana*).

***R. toktoana* S. Y. Kondr., L. Lökös et J.-S. Hur, sp. nov.** (Figure 3)

Mycobank No.: MB 825110.

Similar to *Rufoplaca kaernefeltiana* but different in having well distinct and much larger thallus, thinner and K – cortical layer of thallus, larger and biatorine-like apothecia, lower hymenium and narrower paraphysis tips and shorter and narrower ascospores, and mainly hardly visible and narrower ascospore septum.

**Type:** Republic of Korea, Gyeongsangbuk-do, Ulleung-gun, Dokdo-ri, Seodo Island, on rocks, growing together with *O. yokjidoensis* damaged by *A. dokdoensis*, *Lecanora* sp. and *Physciella* sp. Lat.: 37° 14' 27" N, Long.: 131° 51' 54" E, Alt.: 100 m a.s.l. Coll.: Woo, J. J. (171044), 07.09.2017 (KoLRI 045325 – holotype of *R. toktoana*); the same locality, growing together with *O. yokjidoensis*, Coll.: Woo, J.

J. (171045), 07.09.2017 (KoLRI 045326 – isotype of *R. toktoana*).

**Morphology:** Thallus rather thick, areolate to continuous, whitish gray, or grayish-white; apothecia seem to be biatorine, orange, or somewhat reddish-orange. Thalline areoles (0.5–)1.5–2.5 mm across. Thallus in section to (64–)80–160(–280)  $\mu\text{m}$  thick, cortical layer 8–11.2(–12.8)[–24]  $\mu\text{m}$  thick, very thin, paraplectenchymatous, cell lumina rounded to 4.8  $\mu\text{m}$  in diam.; algal zone filling in the whole thallus below cortical layer to 80(–96)  $\mu\text{m}$  thick; algal cells trebouxoid, 16–19.2(–22.4)  $\mu\text{m}$  in diam.

Apothecia to 0.9–1 mm in diam. and 0.2–0.27 mm thick in section, seem to be biatorine, while lecanorine or zeorine in section; 1–3(–5) per areole; in section thalline exciple to 80–96(–112)  $\mu\text{m}$  thick, cortical layer not distinct or very thin, to 8–16  $\mu\text{m}$  thick, better seen on underside, paraplectenchymatous; true exciple (56–)80–96(–112)[–144]  $\mu\text{m}$  wide in the uppermost lateral portion, more or less scleroplectenchymatous, hyphal lumina to 1.6  $\mu\text{m}$ , and to 16–32(–48)  $\mu\text{m}$  thick in lower lateral and to 16  $\mu\text{m}$  thick in the basal portion, more or less *Blastenia*-type in the latter two portions or scleroplectenchymatous; hymenium 64–72  $\mu\text{m}$  high, epihymenium 8–11.2  $\mu\text{m}$  thick, dark brown; paraphysis tips more or less brownish, richly branched to 2.4–4  $\mu\text{m}$  in diam. in K brownish color disappearing; subhymenium (48–)80–96  $\mu\text{m}$  thick, hyaline, without oil; asci 8-spored, but usually only simple ascospore seen (in K too); ascospores narrowly ellipsoid, mainly simple observed, sometimes becoming slightly darker or slightly brownish (9.6–)11.2–12.8(–14.4)  $\times$  3–4.8  $\mu\text{m}$  in water (45 measurements) and 11.8–13.4(–14.4)  $\times$  3.6–3.9(–4.5)  $\mu\text{m}$  in K (37 measurements); septum very rarely observed, usually seen only at sides of equatorial portions in water to (0.5–)1–2.4  $\mu\text{m}$  wide in water and better seen in K (0.5–)1.5–2(–2.5)  $\mu\text{m}$  thick. Conidiomata and conidia not observed.

**Chemistry:** Epihymenium K + crimson-purple, while brownish color disappearing. Cortical layer of thalline exciple K + purple only in the uppermost lateral portion. Cortical layer of thallus K–.

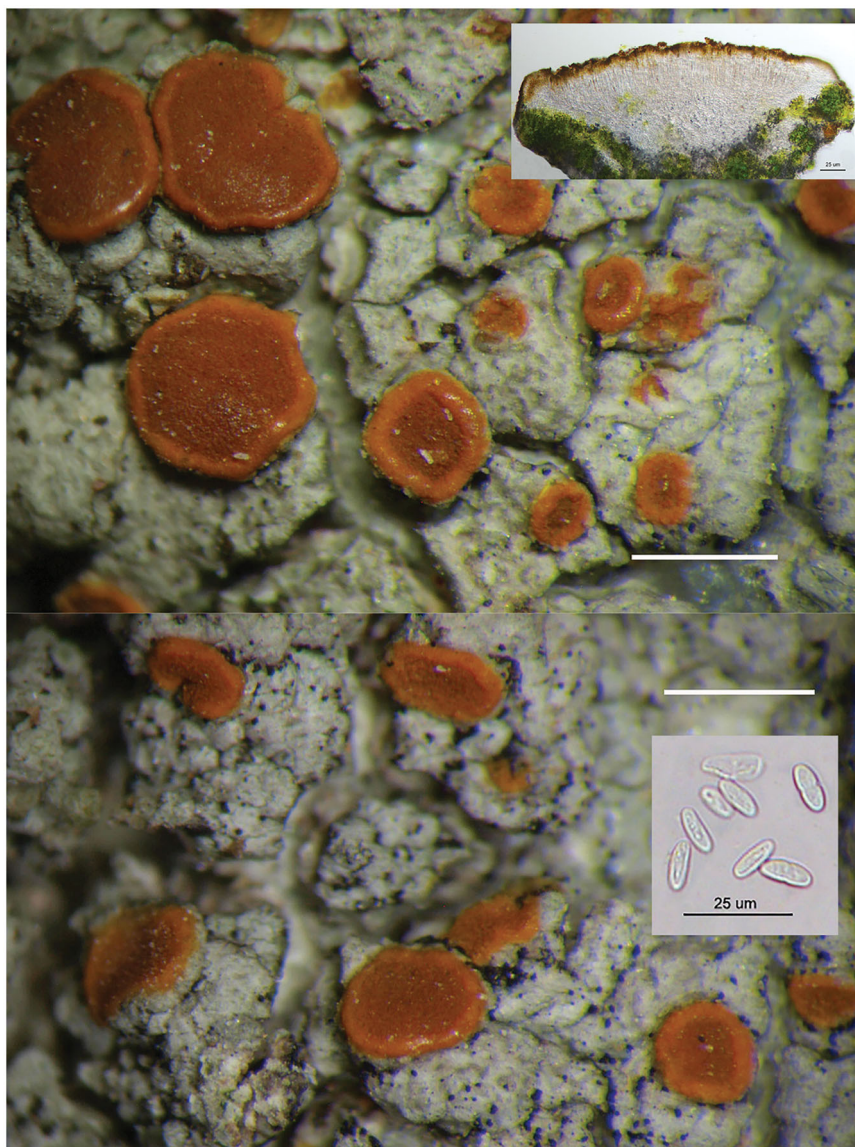
**Ecology:** It grows on siliceous rock in the supralittoral zone.

**Etymology:** It is named after the type locality, namely Dokdo Islands (in Korean Tokto Islands), Republic of Korea, Eastern Asia.

**Distribution:** The species is so far known from the type collection Dokdo Islands, as well as Ulleung-do Island, both the Republic of Korea, Eastern Asia, where it was rather abundant in some places.

**Taxonomic notes:** *R. toktoana* is similar to *R. kaernefeltiana* S. Y. Kondr., L. Lökös et J. S. Hur, recently described from Ulleung-do Island, South Korea (Eastern Asia), but differs in having well distinct





**Figure 3.** *Rufoplaca toktoana* (holotype), general habit with enlarged section of apothecium (top, scale 25 µm) and with enlarged ascospores (bottom, scale 25 µm). Scale 500 µm.

and much larger thallus and larger thalline areoles or often forming almost continuous thallus (thalline areoles (0.5–)1.5–2.5 mm vs. (0.2–)0.4–0.8 mm across, usually very indistinct, distant, and scattered), in having thinner and K– cortical layer of thallus (8–11(–13) µm vs. 30–40(–50) µm thick, K+ purple), in having larger and biatorine-like apothecia (vs. seem to be lecanorine), in having lower hymenium (65–70 µm vs. 70–90 µm high) and narrower paraphysis tips (2.4–4 µm vs. to 5(–6) µm in diam.), and in having shorter and narrower ascospores ((9.5–) 11–13(–14.5) × 3–4.8 µm vs. (10–)12–15(–16) × 7–8 µm) and mainly hardly visible and narrower ascospore septum ((0.5–)1–2.4 µm vs. (4–) 5–6(–7) µm wide) [4].

**Additional specimens examined:** Republic of Korea, Gyeongsangbuk-do, Ulleung-gun, Dokdo-ri, Seodo Island, on rocks, growing together with *Lecanora* cf. *campestris*. Lat.: 37° 14' 27" N, Long.: 131° 51' 54" E, Alt.: 100 m a.s.l. Coll.: Woo, J. J. (171042), 07.09.2017 (KoLRI 045323 sub *Lecanora*

cf. *campestris*); Republic of Korea, Gyeongsangbuk-do, Ulleung-gun, Dokdo-ri, Seodo Island, on rocks, growing together with *Caloplaca dodongensis*. Lat.: 37° 14' 26.66" N, Long.: 131° 51' 51.50" E, Alt.: 20 m a.s.l. Coll.: Lee, B. G. (170909), 07.09.2017 (KoLRI 045190 sub *R. toktoana*); the same locality, growing together with *B. ulleungdoensis*, Coll.: Lee, B. G. (170910, 170911), 07.09.2017 (KoLRI 045191, KoLRI 045192 sub *R. toktoana*); Republic of Korea, Gyeongsangbuk-do, Ulleung-gun, Ulleung-eup, Dodong-ri, Dodong Port, on siliceous rocks. Lat.: 37° 28' 59.9" N, Long.: 130° 54' 40.7" E, Alt.: 20 m a.s.l. Coll.: Kondratyuk, S. Y., Lökös, L. (162040), 11.07.2016 (KoLRI 040278).

### 3.2. Discussion

*A. dokdoensis* is similar to the recently described *A. parietinaria* in having ascomata distributed over the surface of the host thallus, including apothecial



**Table 2.** Comparison of morphological/anatomical characters of *Arthonia dokdoensis*, *A. parietinaria* and *A. molendoi*.

Characters	<i>Arthonia dokdoensis</i>	<i>Arthonia parietinaria</i>	<i>Arthonia molendoi</i>
Infection spots	to 0.5 mm across, often rather indistinct	to 3–5 mm in diam.	to 3–5 mm in across
Mean number of ascomata per infection spot	to 5–10	(10–)20–30(–50)	1–5(–10)
Ascomata (in diam.)	(80–120(–140) $\mu\text{m}$ )	up to 0.25 mm	0.1–0.24 mm
Hymenium ( $\mu\text{m}$ high)	32–40	30–45	45–50
Subhymenium ( $\mu\text{m}$ thick)	64–80	[data not provided in the original description][1]	50–60 $\mu\text{m}$
Ascospores ( $\mu\text{m}$ )	9.6–12.8 $\times$ 4–4.8, hyaline	(9–)10–12(–13.5) $\times$ (3–)4–5(–6), hyaline with thin hyaline perispore (getting condensed and brownish with age)[1]	11–14 $\times$ 5–6.5, slightly pigmented with age
A gelatinous episporic Conidiomata	absent being often aggregated, more common while ascomata rarely observed	usually indistinct while ascomata well developed	present pycnidia of <i>Arthonia molendoi</i> still not observed after Grube [30]
Conidia	bacilliform	ellipsoid; unfortunately measurements on conidia not provided in the original description)[1]	pycnidia of <i>Arthonia molendoi</i> still not observed after Grube [30]
Hosts	<i>Orientophila</i> spp.	<i>Xanthoria parietina</i>	<i>Rusavskia</i> spp.

margins and hymenia, but differs in causing much smaller infection spots (to 0.5 mm across, often rather indistinct, vs. to 3–5 mm in diam.), in having smaller ascomata (80–120(–140)  $\mu\text{m}$  vs. up to 0.25 mm in diam.), in having lower mean number of ascomata per infection spot (to 5–10 vs. (10–)20–30(–50)), in having more common conidiomata being often aggregated, while ascomata rarely observed (vs. ascomata well developed while conidiomata usually indistinct), and in having bacilliform conidia (vs. ellipsoid; unfortunately measurements on the conidia of *A. parietinaria* were not provided in the original description)[1] (Table 2).

*A. dokdoensis* is similar to *A. molendoi* but differs in causing much smaller infection spots (to 0.5 mm in diam. often rather indistinct vs. to 3–5 mm diam. across), in having higher mean number of ascomata per infection spot (5–10 vs. 1–5(–10) in *A. molendoi*), in having smaller ascomata (80–120(–140)  $\mu\text{m}$  vs. 0.1–0.24 mm in diam.), in having lower hymenium (32–40 vs. 45–50  $\mu\text{m}$  high) and thicker subhymenium (64–80  $\mu\text{m}$  vs. 50–60  $\mu\text{m}$  thick), in having shorter and narrower ascospores (9.6–12.8  $\times$  4–4.8  $\mu\text{m}$  vs. 11–14  $\times$  5–6.5  $\mu\text{m}$ ), as well as being hyaline ascospores (not being slightly pigmented with age), and in having bacilliform conidia (pycnidia of *A. molendoi* still not observed after Grube [36]), as well as in the lack of a gelatinous episporic [36].

Unfortunately, a relatively recent full description of *A. molendoi* published only in Grube [36] is still incomplete. Fleischhacker et al. [1] also provided some data on the diagnostic characters of *A. molendoi*. Unfortunately, data on some measurements of ascomata, subhymenium, and shape or morphology of conidia are still missing.

Thus far, all species of the *A. molendoi* aggregation have been recorded from the members of the subfamily Xanthorioideae of the Teloschistaceae (see [2]), i.e., genera *Rusavskia* (type host of *A. molendoi* s. str.), *Xanthoria* (type host of *A. parietinaria*), *Orientophila* (type host of *A. dokdoensis*) and *Calogaya*. On the other hand, material of *A. molendoi* previously recorded from members of the genus *Calogaya* is in urgent need of revision and may belong to another taxon.

The data confirm the conclusion of Grube [36] in that careful studies of the *A. molendoi* complex are still needed in the future to determine if specimens on different lineages in *Caloplaca* and *Xanthoria* belong to the same species.

*Arthonia destruens* differs from taxa of the *A. molendoi* aggr. in having permanently brownish ascospores at overmaturity.

Fleischhacker et al. [1] segregated *Ar. parietinaria* growing on the members of the *Xanthoria* s. str. from the *A. molendoi* complex, which was believed to be foliose lichens of the genera *Xanthoria* and *Rusavskia*, as well as crustose lichens of the genus *Calogaya* (the former *Caloplaca saxicola* group). After segregation of *A. parietinaria* from the complex mentioned, *A. molendoi* is confirmed to *Rusavskia elegans* (type host) and to other species of the genus *Rusavskia*, as well as of the genus *Calogaya*.

The suggestion about the worldwide distribution of *A. parietinaria* and Holarctic is somewhat doubtful given that the host lichen species *Xanthoria parietina* itself is confirmed only from a few collections outside Europe and the Mediterranean region. Most records of *Xanthoria parietina* from outside Europe belong to other taxa (Kondratyuk, in prep.) and even to various genera of the Teloschistaceae in

current stage (see [2]). Fleischhacker et al. [1] hesitated to use modern generic groups of the Teloschistaceae, but the generic groups *Jackelixia*, *Rusavskia*, *Massjukiella*, and *Oxneria*, recently received further confirmation [2,37].

Unfortunately, the diagnostic character of the *A. molendoi* complex, such as fast vine red reaction of hymenium (in contrast to I+blue then red in case of *Arthonia destruens* or *Arthonia incarnata*), was not discussed in the description of *A. parietinaria* [1].

Initially, close relations of the Korean material of *A. dokdoensis* to *Arthonia patellaria* (ITS sequences FR799123, FR799124) were found after ITS phylogeny of the members of the *Arthoniaceae*. On the other hand, only very limited data exists on the ITS nrDNA sequences of the family *Arthoniaceae*, while phylogeny of this family and the entire Arthoniales is built mainly on nrLSU, mtSSU, and RPB2 sequences. An attempt was made to obtain the three sequences mentioned above. On the other hand, only the mtSSU and RPB2 sequences for the new taxon could be obtained.

A separate mtSSU and RPB2 analysis (not shown) revealed that *A. molendoi* is positioned in a separate branch from the *Arthonia* s. str. branch. The same results were obtained in the combined phylogenetic analysis based on concatenated mtSSU and RPB2 sequences (Figure 1).

It was firstly found in this study that the *A. molendoi* group is positioned within the *Bryostigma* clade of the combined phylogenetic tree of the *Arthoniaceae* based on concatenated mtSSU and RPB2 sequences. The *Bryostigma* clade includes the genus *Bryostigma* Poelt et Döbberler with type species *Bryostigma muscigenum* (Th. Fr.) Frisch et G. Thor, as well as members of the *A. molendoi* group [38]. We agree with previous authors [9] that there is probably more than one generic group within the *Bryostigma* clade. Positions of seven of ten taxa of the *Bryostigma* clade are confirmed by combined mtSSU and RPB2 sequences (Figure 1), as well as by nrLSU phylogeny [1].

*A. dokdoensis*, together with the following two species, i.e., *Arthonia phaeophysciae* and *A. parietinaria*, for which molecular data were provided, are the members of the *A. molendoi* complex. Unfortunately, only data on nrLSU sequences of *A. parietinaria* were recorded and illustrated in phylogenetic tree by Fleischhacker et al. [1] from this species of the *A. molendoi* complex. These data could not be obtained from GenBank within this study. *A. epiphyscia*, the position of which should be confirmed by molecular data in the future, is highly likely to be a member of the *Bryostigma molendoi* complex. These taxa, which are characterized by

lichenicolous habit, as well as numerous ascomata forming very characteristic aggregations in host thallus, may be segregated in the future in a separate genus. On the other hand, only insufficient data exist on differences of lichenicolous taxa and lichen-forming fungi of the *Bryostigma* s. l. clade, as well as epibryophilous *Bryostigma muscigenum* (Th. Fr.) Frisch et G. Thor itself (i.e., the genus *Bryostigma* s. str.).

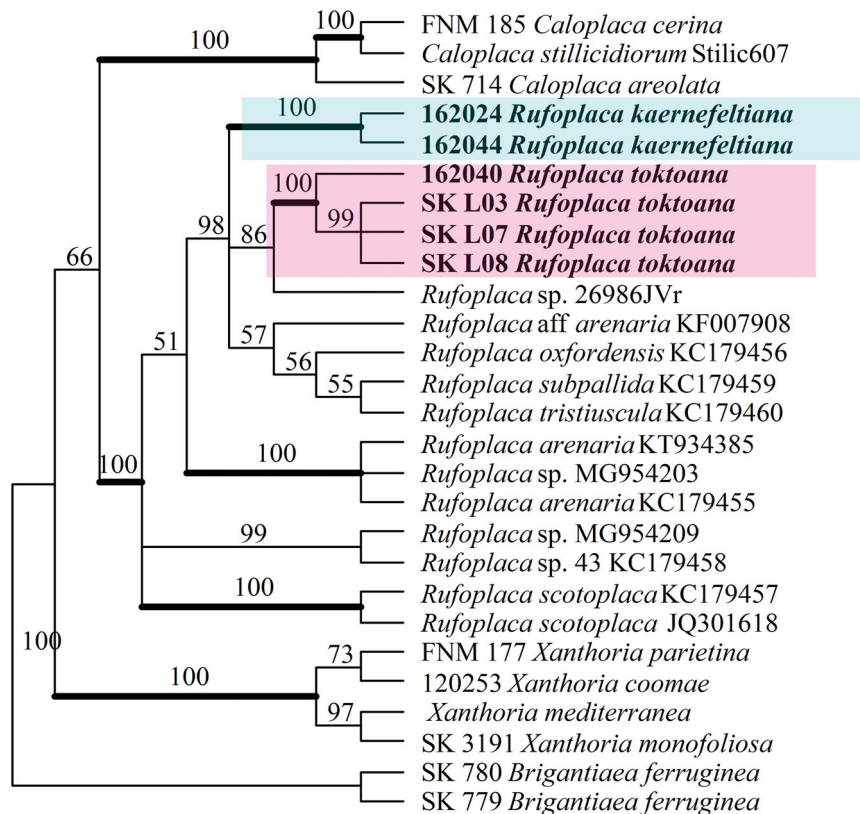
These results provide further evidence for the still incomplete understanding of the character evolution in *Arthonia* s. l. and the relevance of morphological characters used for the delimitation of genera and species groups in *Arthoniaceae*, as was previously shown, e.g., by the studies of Frisch and Thor [39], Frisch et al. [40,41], and Aptroot et al. [42]. Given the combination of morphological characters presented above, in addition to the isolated position on the phylogenetic tree in Figure 1, *A. incarnata* appears to be a rather common species in old-growth forests in Japan (collected only once in Korea) [9], and cannot be connected easily with any of the generic names currently accepted in the synonymy of *Arthonia* [43]. At the current state of knowledge and with a proper revision of *Arthonia* s. l. still pending, this species should be in *Arthonia* for the time being instead of describing it for another poorly monotypic genus.

*R. toktoana* is also similar to the recently described *Rufoplaca ulleungensis* S. Y. Kondr., L. Lökös et J. S. Hur, from Ulleung-do Island, South Korea (Eastern Asia), but differs in having much better developed and often almost continuous thallus (vs. rather indistinct and consisting of distant and scattered areoles), in having larger apothecia (to 0.9–1 mm vs. (0.2–)0.3–0.8 mm diam.), and in having shorter and narrower ascospores ((9.5–) 11–13(–14.5) × 3–4.5 μm vs. 14–16(–18) × 4–5.5(–6) μm), while ascospore septum ((0.5–)1–2.4 μm vs. 1.5–2(–2.5) μm wide) is similar [5] (Table 3).

*R. toktoana* is similar to "*Caloplaca fraudans* (Th. Fr.) H. Olivier growing on sea coastal rock, rarely on wood or bones, in Arctic regions of the Holarctic, but differs in having well distinct, thick thallus, in having concave or plane light reddish orange apothecia (vs. convex, dark orange, or rusty red), in having rather thin own margin and concolorous with apothecium disc (vs. to 0.1–0.2 mm wide slightly shiny and lighter of disc, bright orange, or yellow), in having thinner subhymenium (vs. 60–100(–130) μm thick), in having lower hymenium (65–70 μm vs. 85–100 μm high), in having shorter and narrower ascospores ((9.6–) 11–13(–14.5) × 3–4.8 μm vs. (10–)12–14(–15) × 4–6 μm), and in having slightly narrower (or mainly

**Table 3.** Comparison of morphological/anatomical characters of *Rufoplaca toktoana*, *Rufoplaca kaernefeltiana*, and *Rufoplaca ulleungdoensis*.

Characters	<i>Rufoplaca toktoana</i>	<i>Rufoplaca kaernefeltiana</i>	<i>Rufoplaca ulleungdoensis</i>
Thallus	well distinct and large	usually very indistinct	rather indistinct and consisting of distant and scattered areoles
Thalline areoles mm across	(0.5–)1.5–2.5, well distinct or often forming almost continuous thallus	(0.2–)0.4–0.8, usually very indistinct, distant and scattered	0.3–0.7(–1.3), distant and separate to aggregated in small groups
Cortical layer of thallus (µm thick)	8–11(–13) and K–	30–40(–50), K + purple	7–8 and K–
Apothecia	to 0.9–1 mm, biatorine-like	0.3–0.7 mm, seem to be lecanorine	(0.2–)0.3–0.8 mm, often in groups, biatorine
Hymenium (µm high)	65–70	70–90	70–80
Paraphysis tips (µm in diam.)	2.4–4	to 5(–6)	to 4
Ascospores (µm)	(9.5–) 11–13(–14.5)×3–4.5	(10–)12–15(–16)×7–8	14–16(–18)×4–5.5(–6)
Ascospore septum(µm wide)	(0.5–)1–2.4, mainly hardly visible	(4–) 5–6(–7)	1.5–2(–2.5)

**Figure 4.** Phylogenetic tree of the genus *Rufoplaca* based on ITS nrDNA showing position of the new species *R. toktoana* and the recently described *Rufoplaca kaernefeltiana*.

undeveloped) ascospore septum ((0.5–)1–2.4 µm vs. 2.5–4.5 µm wide) [44].

*R. toktoana* is similar and can be keyed to *Caloplaca erythrocarpa* (Pers.) Zwackh growing on limestones, sandstones enriched by calcium in Europe, the Caucasus, Asia (Syria, Israel, Jordania, and Egypt), and North Africa, but differs in having larger apothecia (0.9–1 mm vs. 0.2–0.5(–0.8) mm in diam.), in having biatorine, but lecanorine or zeorine in section apothecia (vs. zeorine), in having superficial (vs. seem to be immersed) apothecia; in having irregular and larger thalline areoles (0.5–1(–1.5) mm vs. 0.2–0.5(–1) mm across), in having 1 apothecium per areole (vs. (1–)2–3 apothecia per areoles in peripheral and 1(–2) per areoles in the center of thallus); in having dull orange or dull reddish orange disc (vs. dark red, dark rusty red, to

dark rusty brown), in having weakly developed, seen at sides or on underside thalline margin (vs. own margin lighter of disc, red-orange, thin, and permanent), in having narrower and shorter ascospores ((9.6–) 11–13(–14.5)×3–4.8 µm vs. 12–16(–18)×(5–)7–9(–10) µm, and in having narrower ascospore septum ((0.5–)1–2.4 µm vs. 3–5 µm wide [40].

Twenty-five sequences are available for members of the genus *Rufoplaca* in GenBank. The main portion of data was provided by Arup et al. [3], while a few specimens were added by J. Vondrák et al. [17–19]. On the other hand, after ITS phylogeny, the Eastern Asian material, i.e., *R. toktoana* and *R. kaernefeltii*, for which molecular data are for the first time provided in this article, form a separate branch within the genus *Rufoplaca* (Figure 4). Both Eastern Asian taxa have the highest level of



bootstrap support. Therefore, the material of both taxa mentioned is rather homogenous from the molecular point of view.

#### 4. Conclusion

The species diversity of the *Bryostigma* s. lat. clade includes 13 species based on a combined phylogenetic analysis of the *Arthoniaceae* based on mtSSU and RPB2 gene sequences. Data on ITS nrDNA sequences are provided herein for the first time for *A. dokdoensis*, *R. kaernefeltiana*, and *R. toktoana*.

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