Epidemic spread of *Erysiphe corylacearum* in Europe – first records from Germany

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Abstract: Beenken, L., Kruse, J., Schmidt, A. & Braun, U. 2022: Epidemic spread of *Erysiphe corylacearum* in Europe – first records from Germany. Schlechtendalia **39**: 112–118.

Erysiphe corylacearum, an Asian *Corylus* powdery mildew, has been introduced in Europe in recent years. Recently, the occurrence of *E. corylacearum* has also been confirmed for Germany. Phylogeny, taxonomy, host range, distribution, and the epidemic spread of this species in Europe are briefly discussed. The conidial germination pattern is described and illustrated in detail. The identification was confirmed molecularly by sequencing the ITS region.

Zusammenfassung: Beenken, L., Kruse, J., Schmidt, A. & Braun, U. 2022: Epidemische Ausbreitung von *Erysiphe corylacearum*in Europa – erste Nachweise in Deutschland. Schlechtendalia **39**: 112–118.

Erysiphe corylacearum, ein Asiatischer *Corylus*-Mehltau, wurde in den letzten Jahren in Europa eingeschleppt. In jüngster Zeit wurde das Vorkommen von *E. corylacearum* auch für Deutschland nachgewiesen. Phylogenie, Taxonomie, Wirtsspektrum, Verbreitung und die epidemische Ausbreitung dieser Art in Europa werden kurz diskutiert. Die Konidienkeimung wird im Detail beschrieben und abgebildet. Die Identifizierung wurde molekular durch Sequenzierung der ITS-Region bestätigt.

Key words: Powdery mildews, *Erysiphe*, *Corylus avellana*, introduction.

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Erysiphe corylacearum is an Asian powdery mildew species, originally described from Japan on *Corylus heterophylla* as *Microsphaera hommae* (Braun 1982, Braun 1987, Braun & Cook 2012). Braun & Takamatsu (2000) reallocated this species name to *Erysiphe*, which led to the introduction of the illegitimate combination *Erysiphe hommae* (U. Braun) U. Braun & S. Takam. (non *E. hommae* U. Braun). Therefore, Braun (2002) published the replacement name *E. corylacearum*. Bradshaw et al. (2021) treated the phylogeny and taxonomy of this species in the context of *Erysiphe* spp. on *Corylus* and *Ostrya* spp. (*Betulaceae* subfam. *Coryloideae*), including a Chinese sequence retrieved from a specimen on the type host, *Corylus heterophylla*, Japanese sequences obtained from *E. corylacearum* on *Corylus sieboldianus*, and a sequence from this species on *Corylus avellana* introduced in Azerbaijan. In recent years, this species has been introduced in Turkey (Sezer et al. 2017), Azerbaijan (Abasova et al. 2018), Georgia (Meparishvili et al. 2019) and Iran (Arzanlouet al. 2019), and since 2019 also in Europe: Ukraine (Heluta et al. 2019), Austria (Voglmayr et al. 2020, also on *Corylus colurna*), Slovakia (2020, unpublished, sequence deposited in GenBank), Switzerland (Beenken et al. 2020), Italy (Mezzalama et al. 2021), Romania (Chian & Mânzu 2021, Rosati et al. 2021), Spain (Anonymous 2021), and Hungary (Kalmár et al. 2022)]. Therefore, the introduction of this species in Germany was merely a matter of time. Recently, the occurrence of this species in Germany has also been confirmed, based on 66 collections made in Bavaria, Baden-Württemberg and North-Rhine-Westphalia in 2021 and 2022 (Fig. 1, Table 1). The current distribution of *E. corylacearum* in Germany is mainly concentrated in the south of the country, close to the Alps, which is not surprising due to proven occurrences in Austria and Switzerland. In this region, it has also been found outside of urban areas, whereas further north it has only been found sporadically in urban green areas such as parks and private gardens. This spread from south to north and from settlements into the landscape has already been observed in Switzerland (Beenken et al. 2020) where it was at first only found south of the Alps in 2019, but then spread to urban areas north of the Alps. Now in 2022, it is present everywhere in Switzerland, even in forests far from settlements, but also in the alpine region where it occurs at altitudes up to 1450 m (https://swissfungi.wsl.ch/en/distribution-data.html). The pattern and the speed of its propagation suggest that this introduced powdery mildew is not only spread by wind-borne conidia but is also transported by human traffic. Co-infections of the introduced Asian hazelnut powdery mildew and the native *Phyllactinia guttata* (Wallr.) Lév., even on single leaves, are not uncommon. Rather conspicuous infections of *E. corylacearum* mainly occur on the upper leaf surface and less evident *Ph. guttata* symptoms on the underside of the leaves.

Corylus avellana is by far the most common host of *E. corylacearum* in Europe, but it was also found once on its variety *C. a.* var. *heterophylla* and twice on *C. maxima*. In early summer, the asexual morph prevails, whereas the formation of chasmothecia commences in August. The introduction of *E.*

corylacearum in Europe, including Austria, Germany and Switzerland, was characterised by concurrent occurrences of chasmothecia, suggesting that a homothallic powdery mildew species being involved.

Fig. 1: Current distribution of *Erysiphe corylacearum* in Germany. L. Beenken del.

Table 1: Findings of *E. corylacearum* in Germany including GenBank accession numbers of ITS sequences

Location		Host	State	Lat. N	Lon. E	Alt.	Date	Collector	Voucher / GenBank no.
BY	Andechs, garden	*C. a.*	A	47.97424	11.18479	682m	10.08.21	L. Beenken	ZTMyc 66405 / OP554266
BY	Garmisch-Partenkirchen, garden	*C. a.*	T	47.49700	11.10711	710m	09.09.21	J. Kruse	Kruse E1996 / OP554268
BY	Ettal, garden	*C. a.*	T	47.56786	11.09364	875m	10.09.21	J. Kruse	POLL 1001
BY	Ettal, forest	*C. a.*	T	47.57080	11.09937	910m	10.09.21	J. Kruse	
BY	Garmisch-Partenkirchen, forest	*C. a.*	A	47.46560	11.04664	770m	11.09.21	J. Kruse	
BW	Blaubeuren, Asch, garden	*C. m.*	A	48.43979	9.81495	670m	01.10.21	J. Kruse	POLL 1002
BY	München, Allach, garden	*C. a.*	T	48.19200	11.46271	506m	15.10.21	L. Beenken	
BY	München, Allach, garden	*C. a.*	T	48.19449	11.45728	503m	15.10.21	L. Beenken	
BY	München, Allach, park	*C. a.*	T	48.18330	11.45965	508m	16.10.21	L. Beenken	
BY	München, Untermenzing, park	*C. a.*	T	48.17818	11.45982	511m	16.10.21	L. Beenken	
BY	München, Fasanarie, forest	*C. a.*	T	48.19404	11.51922	503m	17.10.21	L. Beenken	
BY	München, Untermenzing, garden	*C. a.*	T	48.18712	11.47333	507m	19.10.21	L. Beenken	
BY	München, Allach, park	*C. a.*	T	48.19227	11.45945	505m	20.10.21	L. Beenken	

BY	München, Moosach, park	*C. a.*	T	48.18686	11.53409	504m	21.10.21	L. Beenken	
BY	München, Englischer Garten, park	*C. a.*	T	48.16157	11.59921	504m	21.10.21	L. Beenken	
BY	Griesen, forest	*C. a.*	A	47.48483	10.9774	806m	21.06.22	J. Kruse	
BY	Garmisch-Partenkirchen, forest	*C. a.*	A	47.51053	11.08324	775m	22.06.22	J. Kruse	
BY	Garmisch-Partenkirchen, garden	*C. a.*	A	47.49069	11.11026	710m	23.06.22	J. Ecker, H. Ostrow	
BY	Garmisch-Partenkirchen, garden	*C. a.*	A	47.53004	11.11285	675m	26.06.22	J. Kruse	
BW	Tübingen, Arboretum	*C. h.*	T	48.53877	9.03136	460m	01.07.22	L. Beenken	ZTMyc 66406 / OP554267
BY	Oberstdorf, Moorbad, forest	*C. a.*	A	47.39833	10.28228	865m	02.07.22	M. Scholler	HAL 63538 F
BY	Oberstdorf, garden	*C. a.*	A	47.40507	10.28019	820m	02.07.22	M. Scholler	KR-M 49349 HAL 63539 F
BW	Konstanz, Litzelstetten, park	*C. a.*	T	47.71921	9.17677	420m	16.07.22	L. Beenken	
BY	Rosenheim, Rimsting, Weingarten	*C. a.*	A	47.87111	12.30389	650m	04.08.22	H. Frauenberger	
BY	Siegsdorf, Bad Adelholzen, forest	*C. a.*	T	47.81115	12.61528	605m	10.08.22	L. Beenken	
BY	Siegsdorf, park	*C. a.*	T	47.82315	12.64188	604m	10.08.22	L. Beenken	
BY	Siegsdorf, park	*C. a.*	T	47.82467	12.64309	602m	10.08.22	L. Beenken	
BY	Siegsdorf, garden	*C. a.*	T	47.82431	12.64441	603m	10.08.22	L. Beenken	
BY	Siegsdorf, park	*C. a.*	T	47.82342	12.64528	605m	10.08.22	L. Beenken	
BY	Siegsdorf, garden	*C. a.*	T	47.82217	12.64348	605m	10.08.22	L. Beenken	
BY	Ruhpolding, park	*C. a.*	T	47.76401	12.64311	661m	10.08.22	L. Beenken	
BY	Ruhpolding, Seehauser forest	*C. a.*	T	47.68850	12.58846	755m	10.08.22	L. Beenken	
BY	Schleching, Oberwössen, forest	*C. a.*	T	47.69293	12.39456	637m	10.08.22	L. Beenken	
BY	Schleching, Mühlbach, garden	*C. a.*	T	47.72523	12.40768	572m	10.08.22	L. Beenken	
BY	Grassau, park	*C. a.*	T	47.77998	12.47074	536m	10.08.22	L. Beenken	
BY	Rosenheim, park	*C. a.*	A	47.85412	12.12782	445m	11.08.22	L. Beenken	
BY	Rosenheim, park	*C. a.*	A	47.85825	12.13463	443m	11.08.22	L. Beenken	
BY	Rosenheim, park	*C. a.*	A	47.85675	12.13696	445m	11.08.22	L. Beenken	
BY	Rosenheim, park	*C. a.*	A	47.85547	12.14095	445m	11.08.22	L. Beenken	
BY	Flintsbach am Inn, garden	*C. a.*	T	47.72197	12.12759	470m	11.08.22	L. Beenken	
BY	Flintsbach am Inn, garden	*C. a.*	T	47.71966	12.12670	475m	11.08.22	L. Beenken	
BY	Flintsbach am Inn, forest	*C. a.*	T	47.71730	12.12832	495m	11.08.22	L. Beenken	
BY	Flintsbach am Inn, forest	*C. a.*	T	47.71653	12.12968	520m	11.08.22	L. Beenken	
BY	Flintsbach am Inn, forest	*C. a.*	T	47.71584	12.13095	530m	11.08.22	L. Beenken	
BY	München, Isar, park	*C. a.*	A	48.12830	11.57741	515m	13.08.22	L. Beenken	
BW	Radolfzell, park	*C. a.*	T	47.73662	8.96428	398m	21.08.22	L. Beenken	
BW	Donaueschingen, park	*C. a.*	T	47.94933	8.50226	680m	21.08.22	L. Beenken	
BW	Singen, park	*C. a.*	T	47.75713	8.83570	427m	21.08.22	L. Beenken	
BW	Singen, park	*C. a.*	T	47.75908	8.83303	431m	21.08.22	L. Beenken	
BW	Freiburg im Breisgau, park	*C. a.*	T	47.99762	7.84559	285m	28.08.22	L. Beenken	
BY	Bad Reichenhall, garden	*C. a.*	T	47.72085	12.87727	473m	07.09.22	L. Beenken	
BY	Bad Reichenhall, park	*C. a.*	T	47.72498	12.87704	470m	07.09.22	L. Beenken	
BY	Bad Reichenhall, Saalach forest	*C. a.*	T	47.74643	12.89926	455m	07.09.22	L. Beenken	
NRW	Bad Honnef, Rhöndorf, park	*C. a.*	A	50.66365	7.20241	55m	11.09.22	J. Kruse	
NRW	Bad Honnef, Rhöndorf, garden	*C. a.*	A	50.66005	7.20953	65m	12.09.22	J. Kruse	
BW	Laufenburg (Baden), park	*C. a.*	T	47.56400	8.05904	320m	18.09.22	L. Beenken	
BW	Laufenburg (Baden), park	*C. a.*	T	47.56459	8.06122	330m	18.09.22	L. Beenken	
BW	Bad Säckingen, park	*C. a.*	A	47.55066	7.94963	295m	18.09.22	L. Beenken	
BW	Bad Säckingen, park	*C. a.*	A	47.55034	7.94806	295m	18.09.22	L. Beenken	
BW	Rottweil, park	*C. a.*	T	48.16233	8.63497	590m	23.09.22	L. Beenken	
BW	Rottweil, park	*C. a.*	T	48.16265	8.63476	590m	23.09.22	L. Beenken	
BW	Tübingen, Bühl, garden	*C. a.*	T	48.48216	8.99276	340m	23.09.22	L. Beenken	
BY	Memmingen, park	*C. a.*	T	47.98794	10.18541	595m	25.09.22	L. Beenken	
BY	Memmingen, park	*C. a.*	T	47.98294	10.17777	600m	25.09.22	L. Beenken	
BY	Memmingen, park	*C. a.*	T	47.98018	10.17992	595m	25.09.22	L. Beenken	
BY	Lindau, park	*C. a.*	T	47.55033	9.68225	395m	25.09.22	L. Beenken	
BY	Lindau, garden	*C. a.*	T	47.55168	9.68944	398m	25.09.22	L. Beenken	

Location: BW = Baden-Württemberg; BY = Bavaria; NRW = North-Rhine-Westphalia; garden = private garden; park = public urban green; forest = non-urban forest and shrubbery.

Host: *C. a.* = *Corylus avellana*; *C. h.* = *C. avellana* var. *heterophylla*; *C. m.* = *C. maxima.*

State: A = only anamorph present; T = teleomorph present.

Voucher: If nothing else is stated, the samples are deposited in the private herbaria of the collectors. Official herbaria abbreviated according to Index Herbariorum (http://sweetgum.nybg.org/science/ih/)

Morphological characteristics

Erysiphe corylacearum U. Braun & S. Takam., Schlechtendalia **8**: 33, 2002 Figs 2–4

≡ *Microsphaera hommae* U. Braun, Mycotaxon **15**: 124, 1982.

≡ *Erysiphe hommae* (U. Braun) U. Braun & S. Takam., Schlechtendalia **4**: 9, 2000, nom. illeg., non *E. hommae* U. Braun, 1981.

= *Microsphaera penicillata* f. *coryli* Jacz., Karm. Opred. Grib., Vip. 2. Muchn.-rosj. griby: 350, 1927.

≡ *Microsphaera coryli* (Jacz.) Golovin, Trudy Bot. Inst. Akad. Nauk S.S.S.R., Ser. 2, Sporov. Rast, **10**: 336, 1956, nom. illeg., non *M. coryli* Homma, 1937.

≡ *Microsphaera variabilis* Y.N. Yu, Acta Microbiol. Sin. **21**(1): 9, 1981 (nom. nov.), non *Erysiphe variabilis* (R.Y. Zheng & G.Q. Chen) U. Braun & S Takam., 2000.

[Based on a specimen from Bavaria (Oberstdorf), deposited at KR-M and HAL (Table 1), A. Schmidt performed detailed germination experiments of conidia: Fresh conidia were dusted on glass slides and deposited on Petri dishes with moist cellulose tissue. In order to observe the conidial germination, the covered Petri dishes were kept at room temperature behind a north-sided window for about 24 hrs. Measurements of conidiophores and conidia were made in tap water based on 25 conidiophores and conidia, respectively.]

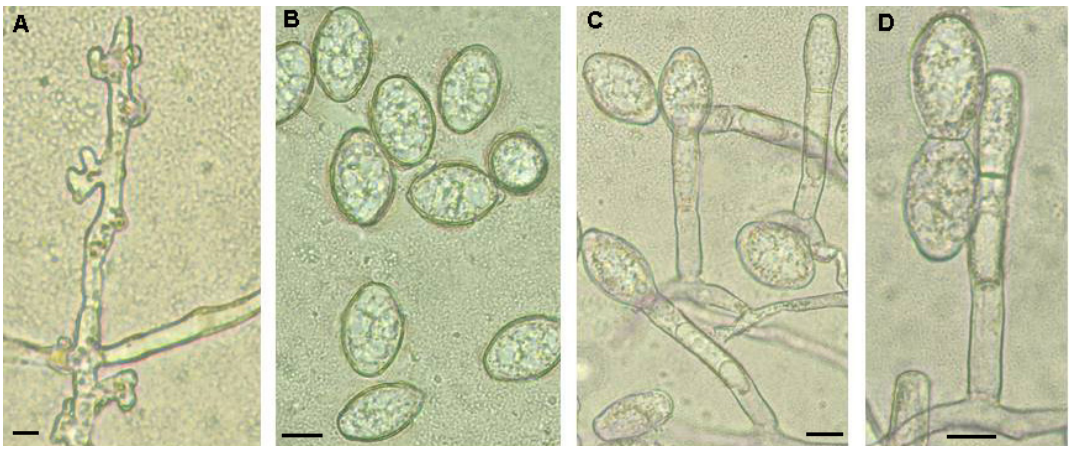

Fig. 2: *Erysiphe corylacearum*. A – Hyphal appressoria. B – Conidia. C and D – Conidiophores. Scale bars: 10 µm. Micrographs: L. Beenken.

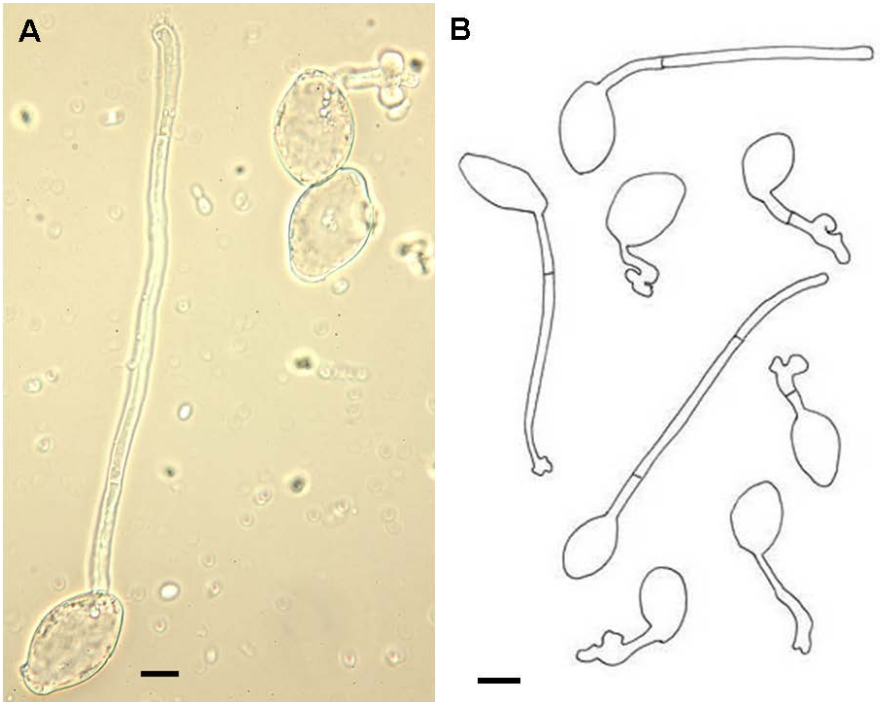

Fig. 3: *Erysiphe corylacearum*. Conidial germination. A – Micrograph (A. Schmidt). B – Drawing (A. Schmidt). Scale bars: 10 µm.

Description: Mycelium on leaves, amphigenous, mainly epiphyllus, forming small to larger white to greyish white thin patches, shape subcircular to irregular, later confluent, sometimes causing brownish violet discolorations of the leaves. Hyphal cells up to 60 µm long and 2–6 µm wide, thin-walled, smooth. Hyphal appressoria solitary or in opposite pairs, almost nipple-shaped to lobate, 3–5 µm diam. Conidiophores arising from the upper surface of hyphal mother cells, mostly towards one septum (non-central), erect, straight, 35–65 µm long; foot-cells straight, cylindrical to somewhat curved or sinuous, 15–35 × 5–7 µm, followed by 1–2 shorter cells, occasionally by a single cell about as long as the foot-cell, basal septum at the junction with the mother cells or somewhat elevated, to 6 µm, occasionally following cells somewhat enlarged, imitating short conidial chains. Conidia formed singly, broad ellipsoid to doliiform-limoniform, fresh conidia 26–32(–36.5) × 16–22 µm, length/width ratio 1.2–2.0, on average 1.5. Conidial germination exhibiting a mixture of the common lobatus pattern and longitubus pattern of the Pseudoidium type, i.e., germ tubes short, with a terminal appressorium, slightly to multilobate, aseptate or with a single septum, to long, with or without terminal appressorium, long germ tubes three to five times as long as the conidial length, up to 155 µm, with a single or two septa. The morphology of the chasmothecia agrees with the description in Braun & Cook (2012: 450): 80–120 µm diam.; appendages up t o 14, 60–100 µm long, brown at the base, apex multiple times regularly dichotomously branched; asci 2–8, obovoid, 40–60 × 30–50 µm; with up to 8 ellipsoid ascospores, 14–20 × 7–14 µm.

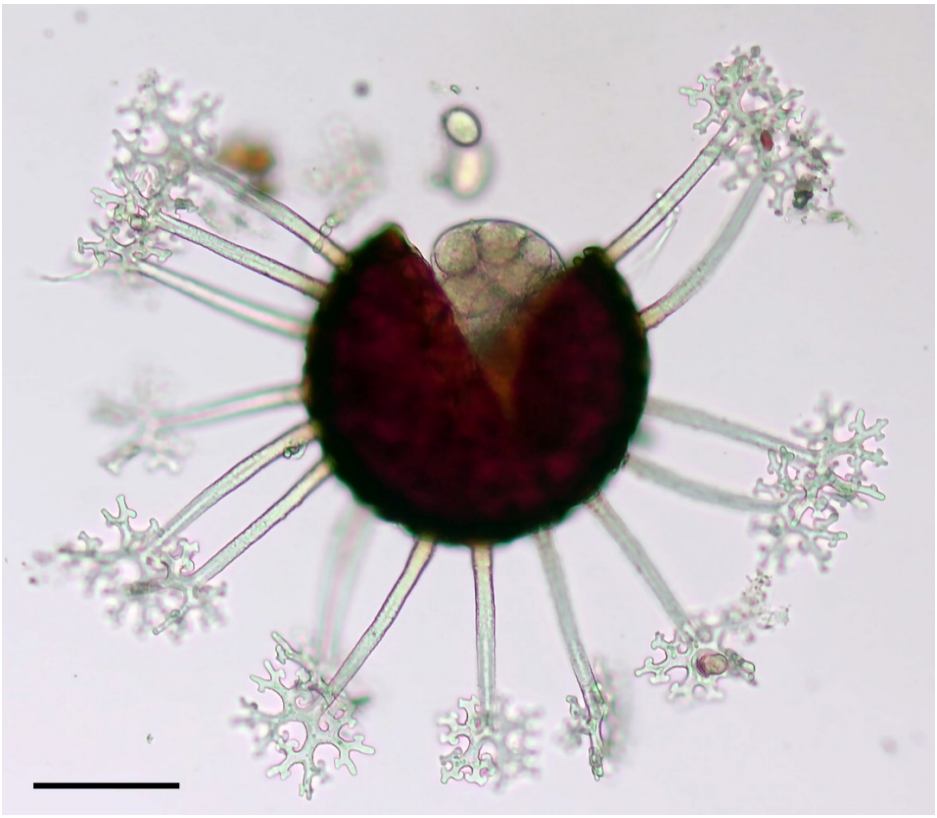

Fig. 4: *Erysiphe corylacearum*. Chasmothecium. Scale bars: 50 µm. Micrograph: L. Beenken.

The gross characteristics of the conidiophores and conidia found in the German collections agree well with the description in Braun & Cook (2012), which was based on Asian specimens. However, Braun & Cook (2012) described somewhat longer and wider foot-cells of the conidiophores, 25–50 × 6–9 µm, and somewhat longer and wider conidia, 30–40 × 18–27 µm. It is possible that this description reflects a higher variability of the anamorph features of this species. However, the description in Braun & Cook (2012) was based on Asian sources and not on own observations. Therefore, it is not quite certain whether this description was, indeed, solely based on *E. corylacearum* or maybe on another Asian *Erysiphe* on *Corylus* or a mixture of two species. In any case, the shape and size of fresh conidia in the German collections agree perfectly with the description given in Voglmayr et al. (2020), based on Austrian samples. Detailed germination experiments with conidia of *E. corylacearum* allowed a comprehensive description of the germination pattern of this species, which largely agrees with the description and illustration in Braun & Cook (2012: 450, fig. 531).

Molecular investigations

The two first German findings of *E. corylacearum* occurring on *C. avellana* in Andechs (ZT Myc 66405) and Garmisch-Partenkirchen (Kruse E1996), as well the sample on *C. avellana* var. *heterophylla* found in Tübingen (ZT Myc 66406) were molecularly examined. The ITS1-5.6S-ITS2 region of nrDNA was sequenced using the powdery mildew specific primer pairs PMITS1/PMITS2 (Cunnington et al. 2003) and PM11/PM10 (Bradshaw & Tobin 2020), respectively, following Beenken (2017). Resulting ITS sequences were deposited in GenBank (accession numbers OP554266–554268). The entire ITS1-5.6S-ITS2 sequences, as well as the separate ITS2 sub-sequences were compared by a BLAST search (search option blastn, Altschul et al. 1990) against the NCBI nucleotide database GenBank, with the result that the three German full-length ITS sequences showed 100% identity to sequences of *E. corylacearum* stored in GenBank from Austria (MW031866), Azerbaijan (LC270863), Georgia (MK157199), Iran (MH047243), Hungary (OL744964), Italy (MW045425), Romania (MW590690), Slovakia (MT176105), Switzerland (MN822721) and Turkey (MW341489). The ITS2 sequence of them is 100% identical to the corresponding part of the sequence of *E. corylacearum* on *Corylus sieboldiana* from Japan (MT095104).

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