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ORIGINAL ARTICLE

Notes on powdery mildews (Erysiphales) in Thailand III. *Erysiphe* species on Fabaceae, Fagaceae, Hydrangeaceae and Lamiaceae

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Abstract This report provides morphological descriptions of powdery mildew specimens found on Fabaceae, Fagaceae, Hydrangeaceae and Lamiaceae and molecular phylogenetic analyses based on ITS rDNA sequences. These include 4 new host records for *Erysiphe* species in the world, viz., *Desmodium triflorum* (Fabaceae), *Microtoena insuavis* (Lamiaceae) and *Mucuna bracteata* (Fabaceae). *Aeschynomene americana* var. *americana* (Fabaceae), *Sesbania grandiflora* (Fabaceae) and *Tamarindus indica* (Fabaceae) are new host for *Erysiphe trifoliorum* s. lat. and *Phanera purpurea* (Fabaceae) is new host for *Erysiphe lespedezae*. In addition, 11 records of *Erysiphe* species new to Thailand were described.

Keywords Anamorph · Biodiversity · *Erysiphaceae* · Molecular phylogeny · Tropics

Introduction

Recently, new checklists of powdery mildews belonging to the genera *Erysiphe* and *Podosphaera* sect. *Podosphaera* were reported from Asia (Meeboon et al. 2016; Meeboon and Takamatsu 2016). These reports as well as those from Siahaan et al. (2016a, b) suggest that there are much more undescribed species of powdery mildews in Southeast Asia region than previously thought. This is supported by recent publications from this region, in particular from Indonesia and Thailand (To–anun et al. 2003, 2005; Divarangkoon et al. 2011; Monkhung et al. 2011, 2013; Meeboon et al. 2012a, b, c, d, 2013; Hidayat et al. 2014; Siahaan et al. 2015). In this paper, we report an additional list about *Erysiphe* species found on Fabaceae, Fagaceae, Hydrangeaceae and Lamiaceae in Thailand.

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Materials and methods

Morphological examination

Morphological examinations were conducted according to the procedure described by Meeboon and Takamatsu (2015). Rehydration of mycelium from herbarium specimen was conducted according to the method described by Shin and La (1993). Thirty conidia and conidiophores were measured for each specimen. Specimens were deposited at Mie University Mycological Herbarium (TSU-MUMH), Japan.

Molecular phylogeny

Whole cell DNA was extracted from mycelia using the Chelex method (Walsh et al. 1991) as described in Hirata and Takamatsu (1996). The respective primer pairs of PM5/ITS4 and ITS5/PM6 (Takamatsu and Kano 2001) were used to amplify ITS fragment 1 and fragment 2, respectively. PCR reaction was conducted using KOD FX Neo DNA polymerase (Toyobo, Japan) according to the manufacturer's protocol. The PCR product was sent to SolGent Co. Ltd. for sequencing using primer pair of ITS1 and ITS4 (White et al. 1990).

New representative sequences determined in this study were deposited in DNA Data Base of Japan (DDBJ) under the accession numbers of AB237804, AB237805, LC163907,

LC163908, LC163912, LC163914, LC163915 and LC163916. Sequences generated in this study were aligned with other sequences of *Erysiphe* retrieved from DNA databases (DDBJ, EMBL, NCBI) using MUSCLE (Multiple Sequence Comparison by Log Expectation) (Edgar 2004) implemented in MEGA 6 (Tamura et al. 2013). The alignments were deposited in TreeBASE (http://www.treebase.org/) under the accession number of S20133. Phylogenetic trees were obtained from the data set using the maximum parsimony (MP) method in PAUP* 4.0b10 (Swofford 2002) as described in Meeboon and Takamatsu (2016).

Results

Taxonomy

Fabaceae

1. ***Erysiphe* sp. ex *Pueraria mirifica***

Mycelium epiphyllous, white, persistent, thin, effuse, sometimes covering entire leaves; *hyphae* 6–8 μm wide, branched, septate, hyaline, thin-walled, smooth; *hyphal appressoria* slightly to distinctly lobed, usually solitary; *conidiophores* up to about 160 μm long, erect, arising from the upper surface of mother cells; *foot cells* 40–70 × 6–9 μm, straight, occasionally slightly flexuous-sinuous, cylindrical, followed by 0–2 shorter cells, forming conidia singly; *conidia* 30–40 × 15–20 μm, ellipsoid to cylindrical; *germ tubes* subterminal, short, with lobed appressoria (*Pseudoidium* type) (Fig. 1).

Material: On *Pueraria mirifica* Airy Shaw & Suvatab. (Fabaceae), THAILAND, Chiang Mai province, Suthep, 15 January 2015, J. Meeboon, MUMH3759.

Note: *Erysiphe puerariae* R.Y. Zheng & G.Q. Chen is the only *Erysiphe* species found on *Pueraria* (Braun and Cook 2012). This species is endemic to China. However, there is no information on asexual morph of this species. Unfortunately, we failed to obtained DNA sequence of this fungus. This is the first report of *Erysiphe* sp. on *Pueraria mirifica* from Thailand.

2. ***Erysiphe lespedezae*** R.Y. Zheng & U. Braun **ex *Phanera purpurea***

Mycelium amphigenous, mainly epiphyllous, white to greyish white, persistent, effuse to dense; *hyphae* 3.5–8 μm wide, ± straight, occasionally geniculate-sinuous; *hyphal appressoria* lobed to multilobed, solitary or in opposite pairs; *conidiophores* 48–94 μm long, erect, arising from the upper part of mother cells, position central or non-central; *foot cells* 35–65 × 5–9 μm, basal septum 5–20 μm distant from the branching point with the supporting hypha, slightly curved, forming conidia singly, followed by 1–3 shorter cells, with a basal septum at the branching point of the mycelium; *conidia* 19–41 × 10–17 μm, cylindric-ovoid; *germ tubes* subterminal, with lobed appressoria (*Pseudoidium* type) (Fig. 2).

Material: On *Phanera purpurea* L. (Fabaceae), THAILAND, Chiang Rai province, 28 December 2015, J. Meeboon, MUMH1816, accession number: LC163912; MUMH5742; MUMH6622, accession number: LC163921.

Note: Two powdery mildew species, i.e., *Ps. bauhiniae* (G.J. M. Gorter & Eicker) U. Braun & C.T.A. Cook and *Ps.*

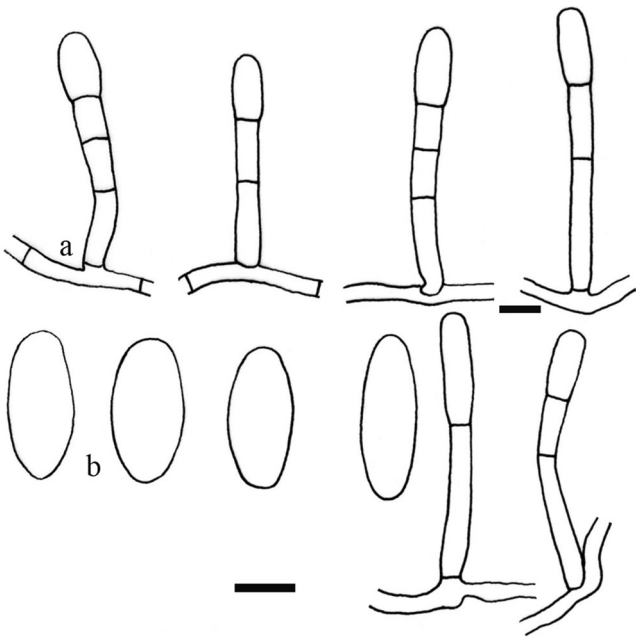

Fig. 1 *Erysiphe* sp. on *Pueraria mirifica*. **a** conidiophores. **b** conidia. Bars 20 μm

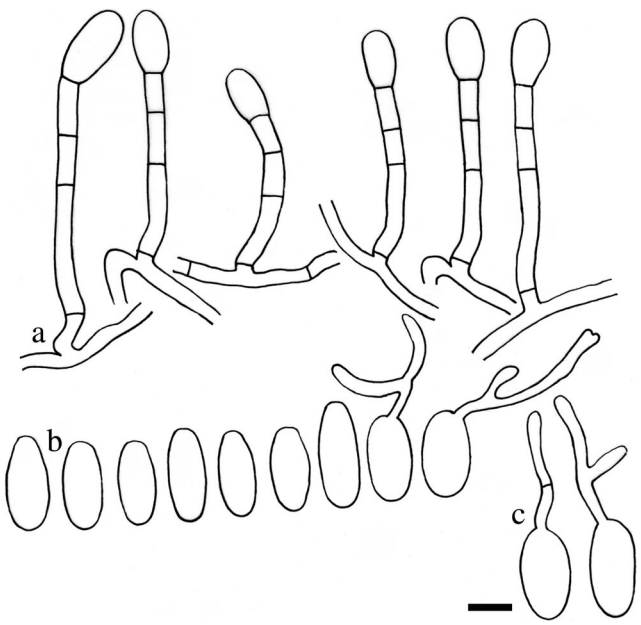

Fig. 2 *Erysiphe lespedezae* on *Phanera purpurea*. **a** conidiophores. **b** conidia. **c** appressoria. Bar 20 μm

caesalpiniacearum (Hosag. & U. Braun) U. Braun & R.T.A. Cook have been recorded on *Phanera* spp. (Braun and Cook 2012). *Pseudoidium bauhiniae* differs from *Ps. caesalpiniacearum* by having multilobed appressoria. The morphological characteristics of this specimen are similar to *Ps. bauhiniae* (Braun and Cook 2012). Siahaan et al. (2016b) reported *P. purpurea* as a host of *E. quercicola*. *Erysiphe lespedezae* differs from *E. quercicola* by having conidia cylindric-ovoid while ellipsoid-doliiform in *E. quercicola*, longer conidiophores [48–94 vs. 32–72 μm in *E. quercicola*] and foot cells [35–65 × 5–9 μm vs. 8–30 × 5–8 μm in *E. quercicola*]. This report clearly indicates that two *Pseudoidium* species infect *P. purpurea*. The phylogenetic analysis based on ITS sequence showed that this fungus is identical to *E. lespedezae* R.Y. Zheng & U. Braun on *Lespedeza thunbergii* (AB015923) (Fig. 19). Based on the morphological and molecular characteristics, this fungus was identified as *E. lespedezae*. This is the first report of *E. lespedezae* on *P. purpurea* in the world.

3. ***Erysiphe trifoliorum* s. lat. ex *Sesbania grandiflora***

Mycelium epiphyllous, white, forming dense patches; *hyphae* 4–8 μm wide; *hyphal appressoria* moderately lobed, solitary or in opposite pairs; *conidiophores* 75–120 μm long, erect, arising from the upper surface of mother cells; *foot cells* 28–56 × 8–11 μm, slightly straight to somewhat curved-sinuous, followed by 1–2 shorter cells, forming conidia singly; *conidia* 35–45 × 15–20 μm, ellipsoid-ovoid to cylindrical-doliiform; *germ tubes* almost terminal, short to long, with lobed appressoria (*Pseudoidium* type) (Fig. 3).

Material: On *Sesbania grandiflora* (L.) Poir (Fabaceae), THAILAND, Chiang Mai province, Suthep, 14 March 2014, J. Meeboon, MUMH1779, accession number: LC163908.

Note: *Erysiphe sesbaniae* Wolcan & U. Braun and *Ps. fabacearum* (Hosag.) U. Braun & R.T.A. Cook are recorded on *Sesbania* species worldwide (Braun and Cook 2012). Powdery mildew on *S. grandiflora* was previously reported as *Oidium* sp. in Thailand. The phylogenetic tree constructed by the parsimony method showed that sequence of this fungus nested in the *E. trifoliorum* s. lat. clade (Takamatsu et al. 2015) from various hosts. Therefore, the current specimen is determined as *E. trifoliorum* s. lat.

4. ***Erysiphe trifoliorum* s. lat. ex *Tamarindus indica***

Mycelium amphigenous, mainly epiphyllous, white, persistent, effuse or in dense, confluent patches, sometimes covering entire leaves; *hyphae* 3–7 μm wide, branched, septate; *hyphal appressoria* lobed, solitary or in opposite pairs; *conidiophores* 50–130 μm long, erect, arising from the upper surface of mother cells, basal septum at the junction with the mother cell or slightly elevated; *foot cells* 25–70 × 5–8.5 μm, straight, cylindrical, occasionally slightly curved, followed by 0–2 shorter cells, with a basal septum at the branching point of the mycelium, forming conidia singly; *conidia* 28–45 × 15–19.5 μm, ellipsoid-ovoid to cylindrical; *germ tubes* ± terminal, with lobed appressoria (*Pseudoidium* type) (Fig. 4).

Material: On *Tamarindus indica* L. (Fabaceae), THAILAND, Chiang Mai province, Suthep, 18 January 2006, J. Meeboon, MUMH1750, accession number: LC163908.

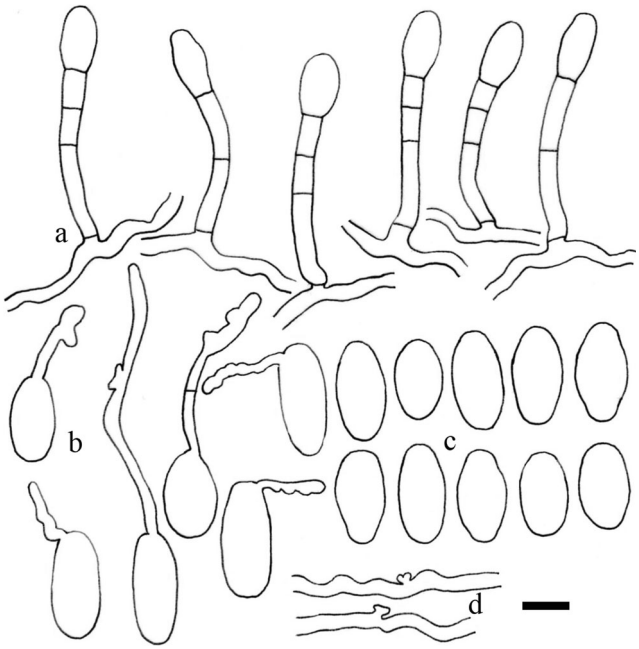

Fig. 3 *Erysiphe trifoliorum* s. lat. on *Sesbania grandiflora*. **a** conidiophores. **b** germ tubes. **c** conidia. **d** appressoria. Bar 20 μm

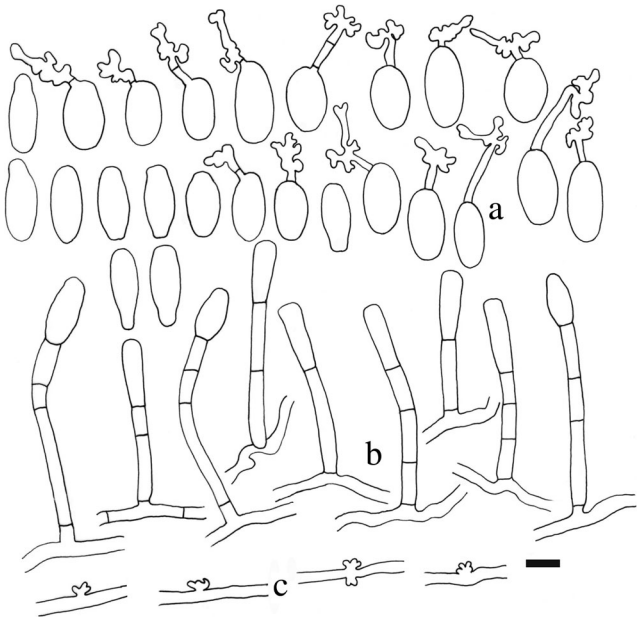

Fig. 4 *Erysiphe trifoliorum* s. lat. on *Tamarindus indica*. **a** conidia and germ tube. **b** conidiophores. **c** appressoria. Bar 20 μm

Note: Yen (1966) reported the powdery mildew on *Tamarindus indica* as a new variety, *Oidium erysiphoides* f. *tamarindi* J.M. Yen. Braun (1982) revised the name as *O. tamarindi* (J.M. Yen) U. Braun. Braun and Cook (2012) revised this name to *Ps. tamarindi* (J.M. Yen) U. Braun & R.T.A. Cook. This species distributes in Asia (India, Java, Singapore, Sri Lanka, Taiwan), Africa (Ghana, South Africa) and North America (Maxico). Recently, *E. quercicola* was found on *T. indica* (unpublished data by the authors). *Erysiphe trifoliorum* s. lat. differs from *E. quercicola* by having conidia ellipsoid-ovoid to cylindrical while ellipsoid-doliiform in *E. quercicola*. This report clearly indicates that two *Pseudoidium* species infect *T. indica*. This is the first report of *E. trifoliorum* s. lat. on *T. indica* in the world.

5. ***Erysiphe pisi*** **DC. ex** ***Pisum sativum***

Mycelium amphigenous, persistent or evanescent, effuse or in thin, irregular patches; *hyphal cells* 4–7 μm; *hyphal appressoria* lobed, solitary, occasionally in opposite pairs; *conidiophores* 76–125 μm long, erect, arising mostly centrally or somewhat laterally from top of mother cell; *foot cells* 35–70 × 8–12.5 μm, cylindrical, straight, curved or somewhat flexuous-sinuous, followed by 0–2 cells, usually shorter, sometimes about as long as the foot cell, forming conidia singly; *conidia* 30–44 × 18–20 μm, ellipsoid-ovoid to doliiform (Fig. 5).

Material: On *Pisum sativum* L. (Fabaceae), THAILAND, Chiang Mai province, Suthep, 25 December 2013, J. Meeboon, MUMH1850, accession number: LC163915.

Note: *Erysiphe glycines* F.L. Tai and *E. pisi* DC. are recorded on *P. sativum* worldwide (Braun and Cook 2012). There is a record of *E. pisi* on *P. sativum* in Thailand. Falloon et al. (1989) studied asexual morph of *E. pisi* on *P. sativum* by scanning electron microscopy. The asexual morph of the present specimen are in good agreement with *E. pisi*. The ITS sequence showed that this fungus is identical to *E. pisi* on *P. sativum* and *Lathyrus latifolius* (Fig. 19). Based on the morphological characteristics and molecular analysis, this fungus is identified as *E. pisi*.

6. ***Erysiphe quercicola*** S. Takam. &. U. Braun **ex** ***Acacia auriculaformis***

Mycelium epiphyllous, persistent or evanescent, effuse or in patches, often covering the entire surface of the leaves; *hyphal cells* 5–8 μm; *hyphal appressoria* slightly lobed to multilobed, solitary or in opposite pairs; *conidiophores* 80–130 μm long, erect, arising centrally or laterally from the upper surface of the mother cell; *foot cells* 25–45 × 10–12 μm, cylindrical, straight to sometimes curved, followed by 1–3 shorter cells or cells of about the same length, forming conidia singly; *conidia* 27.5–42 × 16–17.5 μm, ellipsoid-ovoid-cylindrical or doliiform; *germ tubes* ± terminal, with lobed appressoria (*Pseudoidium* type) (Fig. 6).

Material: On *Acacia auriculaformis* A. Cunn. (Fabaceae), THAILAND, Bangkok province, Chatuchack, 17 February 2014, J. Meeboon, MUMH1805, accession number: AB237804; MUMH5752, accession number: AB237805.

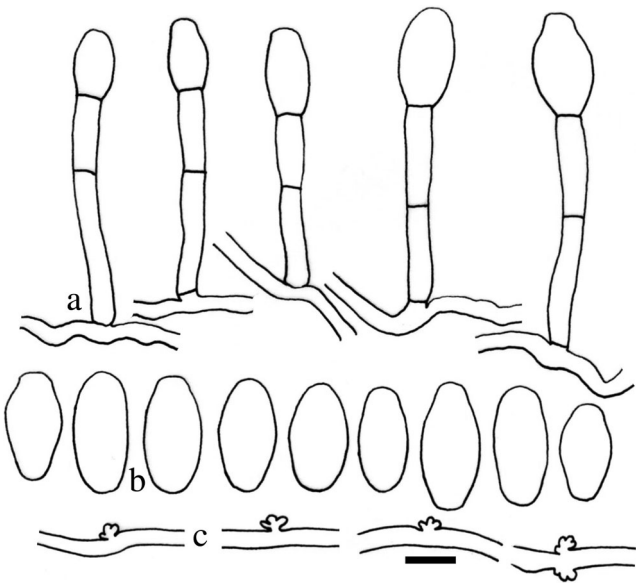

Fig. 5 *Erysiphe pisi* on *Pisum sativum*. **a** conidiophores. **b** conidia. **c** appressoria. Bar 20 μm

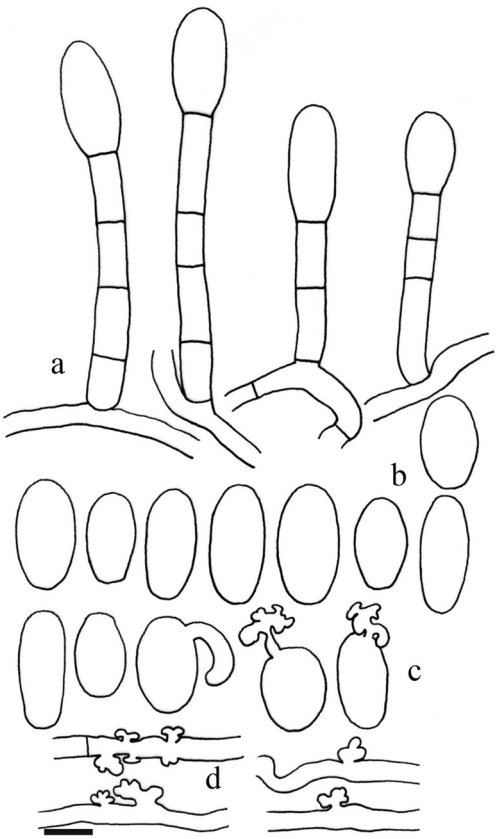

Fig. 6 *Erysiphe quercicola* on *Acacia auriculaformis*. **a** conidiophores. **b** conidia. **c** germ tubes. **d** appressoria. Bar 20 μm

Note: *Erysiphe acaciae* S. Blumer, *E. pisi* var. *pisi* DC., *E. polygoni* DC. and *E. trifoliorum* (Wallr.) U. Braun have been recorded as *Erysiphe s. lat*. on *Acacia* spp. worldwide (Braun and Cook 2012; Farr and Rossman 2016). Because sexual morph was not found in the present fungus, only asexual morph was described in detail. The phylogenetic tree showed that this fungus nested in the large clade of *E. quercicola* from various hosts with 100% BS (Fig. 19). Based on this analysis, the current specimen is assigned as *E. quercicola*.

7. ***Erysiphe trifoliorum* s. lat. ex *Aeschynomene americana* var. *americana***

Mycelium amphigenous, effuse or in patches, evanescent to persistent; *hyphal cells* 5–7.5 μm wide; *hyphal appressoria* lobed, solitary, occasionally in opposite pairs; *conidiophores* 100–135 μm long, erect, arising mostly centrally or somewhat laterally from top of mother cell; *foot cells* 30–65 × 8–11 μm, cylindrical, straight, curved or somewhat flexuous-sinuous, followed by 1–2 cells, usually shorter, sometimes about as long as the foot cell, forming conidia singly; *conidia* 30–45 × 12–22 μm, ellipsoid-ovoid to cylindric; *germ tubes* ± terminal, short, with lobed appressorium (*Pseudoidium* type) (Fig. 7).

Material: On *Aeschynomene americana* var. *americana* L. (Fabaceae), THAILAND, Chiang Mai province, Mae Jo, 22 December 2014, J. Meeboon, MUMH1841, accession number: LC163914.

Note: Three species of *Aeschynomene*, viz., *A.americana*, *A. indica*, and *A. virginica*, are infected with powdery mildews throughout the world (Amano 1986; Braun and Cook 2012). Shin (1988) also reported *E. pisi* on *A. indica* in Korea. Asexual morph of *E. pisi* were somewhat different from this fungus in its larger conidia (mostly 32–48 × 16–20) and longer conidiophores (mostly 70–120 × 7–8(−10)). The sequence from this specimen nested in the *E. trifoliorum* s. lat. clade (Takamatsu et al. 2015) from various hosts. Therefore, the current specimen is tentatively determined as *E. trifoliorum* s. lat. This is the first report of *E. trifoliorum* s. lat. on *A. americana* in Thailand.

8. ***Erysiphe* sp. ex *Indigofera dosua***

Mycelium amphigenous, mainly hypophyllous, effuse or in patches, thin, evanescent, often covering the entire leaf surface; *hyphal cells* 3.5–6.5 μm long, hyaline, thin-walled, smooth; *hyphal appressoria* lobed, solitary or in opposite pairs; *conidiophores* 42.5–91 μm long, erect, arising ± centrally from upper surface of the mother cell; *foot cells* 20–60 × 7.5–9 μm, straight, cylindrical, followed by 1–2 cells shorter, forming conidia singly; *conidia* 25–38 × 16–20 μm, ellipsoid-ovoid, subcylindrical; *germ tubes* almost terminal, short to moderately long, with lobed appressoria (*Pseudoidium* type) (Fig. 8).

Material: On *Indigofera dosua* Buchanan-Hamilton ex D. Don (Fabaceae), THAILAND, Chiang Mai province, Suthep, 10 February 2014, J. Meeboon, MUMH3755.

Note: Based on conidiophore morphology and conidial germination patterns, this fungus belongs to the genus *Pseudoidium*, asexual morph of *Erysiphe*. This is the first report of *Erysiphe* on *I. dosua* in Thailand.

9. ***Erysiphe* sp. ex *Indigofera linnaei***

Mycelium amphigenous, mainly hypophyllous, thin, evanescent, persistent, effuse or in patches, often covering the entire leaf surface; *hyphal cells* 3.5–5 μm wide; *hyphal appressoria* lobed, solitary or in opposite pairs; *conidiophores* 42–82 μm long,

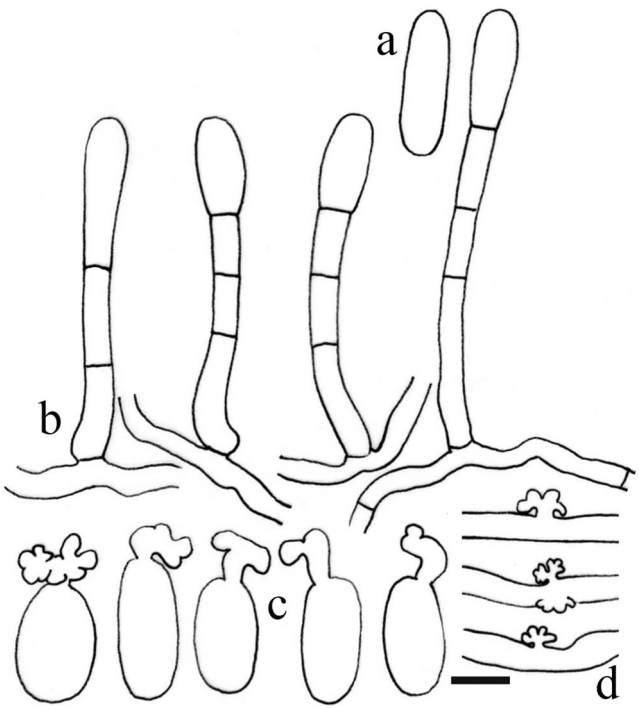

Fig. 7 *Erysiphe trifoliorum* s. lat. on *Aeschynomene americana* var. *americana*. **a** conidia. **b** conidiophores. **c** germ tubes. **d** appressoria. Bar 20 μm

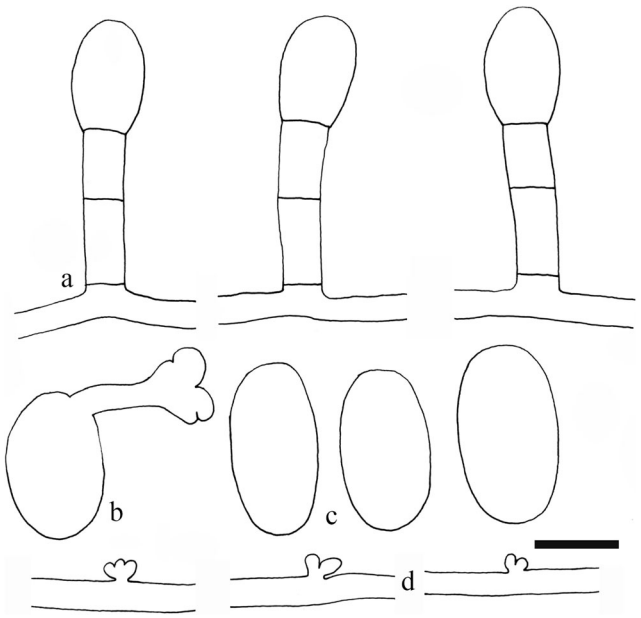

Fig. 8 *Erysiphe* sp. on *Indigofera dosua*. **a** conidiophores. **b** germ tube. **c** conidia. **d** appressoria. Bar 20 μm

erect, arising ± centrally from upper surface of the mother cell; *foot cells* 18–35 × 8–10 μm, usually sinuous to almost straight, followed by 1–2 cells shorter or occasionally about the same length, forming conidia singly; *conidia* 28–40 × 15–20 μm, ellipsoid-ovoid to sub-cylindrical; *germ tubes* almost terminal, moderately long, with lobed appressoria (*Pseudoidium* type) (Fig. 9).

Material: On *Indigofera linnaei* Ali (Fabaceae), THAILAND, Chiang Mai province, Mae Rim, 20 January 2014, J. Meeboon, MUMH1746.

Note: Yen (1966) described anamorphic characteristics of *Oidium indigoferae* on *Indigofera hirsute* in Asia (Singapore). This species is also reported in Australia and Africa (Ghana, South Africa) (Braun 1987). The teleomorphic state of this fungus was first described by Shin (1988) on *I. kirilowii* in Korea, and named a new species *Microsphaera indigoferae* H.D. Shin & Y.J. La [= *Erysiphe indigoferae* (H.D. Shin & Y.J. La) U. Braun & S. Takam]. This species is also reported in Asia (Indonesia, Japan, China, incl. Taiwan, India, Singapore), Africa (Ghana, India, Kenya, Kongo, Mauritius, Niger, Sierra Leone, South Africa, Tanzania, Zambia, Zimbabwe) and Australia (Shin 2000; Braun and Cook 2012). Based on conidiophore morphology and conidial germination patterns, this fungus belongs to the genus *Pseudoidium*, asexual morph of *Erysiphe*. This is the first report of *Erysiphe* sp. on *I. linnaei* in Thailand.

10. ***Erysiphe* sp. ex *Pueraria wallichii***

Mycelium epiphyllous, thin, persistent, in white patches or effuse, sometimes covering entire leaves; *hyphae* 3–5 μm wide, branched, septate, hyaline, thin-walled, smooth; *hyphal appressoria* lobed, usually solitary; *conidiophores* up to about 100 μm long, erect, arising from the upper surface of mother cells; *foot cells* 30–50 × 6–8 μm, straight, occasionally slightly flexuous, cylindrical, followed by 1–2 usually shorter cells, following cells occasionally about as long as the foot cell or rarely longer, forming conidia singly; *conidia* 25–40 × 18–20 μm, ellipsoid to cylindrical; *germ tubes* subterminal, short, with lobed appressoria (*Pseudoidium* type) (Fig. 10).

Material: On *Pueraria wallichii* DC. (Fabaceae), THAILAND, Chiang Mai province, Suthep, 10 February 2014, J. Meeboon, MUMH6636.

Note: *Erysiphe puerariae* R.Y. Zheng & G.Q. Chen is the only *Erysiphe* species found on *Pueraria* (Braun and Cook 2012). However, we could not compare the morphological characteristics of the current specimen with *E. puerariae* due to lacking of asexual morph of this species. This is the first report of *Erysiphe* sp. on *P. wallichii* in Thailand.

11. ***Erysiphe* sp. ex *Clitoria ternatea***

Mycelium epiphyllous, effuse, evanescent to persistent, often following veins, sometimes covering the entire leaf surface; *hyphae* 5–6 μm wide, hyaline, branched; *hyphal appressoria* moderately lobed; *conidiophores* 81–143 μm long, erect, arising from the upper surface of mother cells; *foot cells* 28–62 × 7.5–10 μm, cylindrical, straight to slightly flexuous, followed by 1–3 usually shorter cells, occasionally by a cell of about the same length, forming conidia singly; *conidia* 30–51 × 17.5–21 μm, ellipsoid-ovoid (Fig. 11).

Material: On *Clitoria ternatea* L. (Fabaceae), THAILAND, Chiang Mai province, Suthep, 10 February 2014, J. Meeboon, MUMH3819.

Note: *Pseudoidium clitoriae* (Narayanas. & K. Ramakr.) U. Braun & R.T.A. Cook was reported as *Pseudoidium* on *Clitoria*

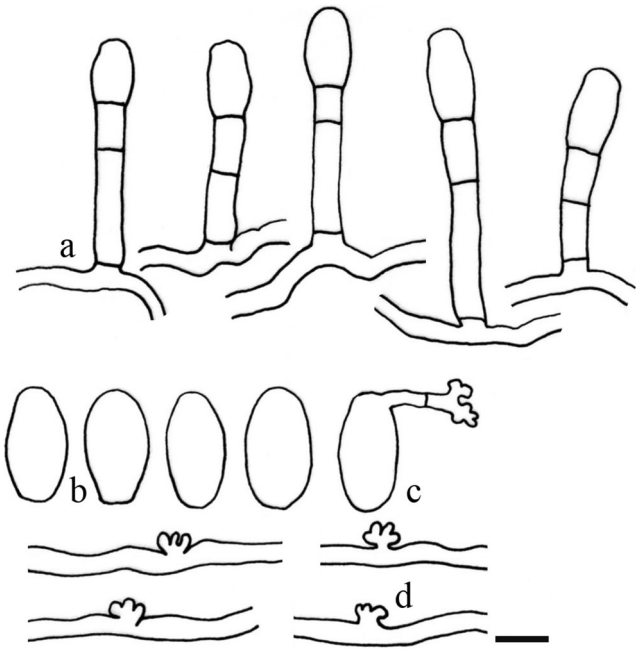

Fig. 9 *Erysiphe* sp. on *Indigofera linnaei*. **a** conidiophores. **b** conidia. **c** germ tubes. **d** appressoria. Bar 20 μm

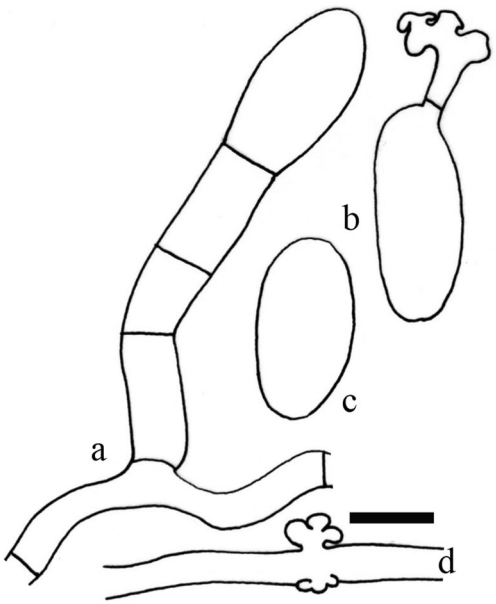

Fig. 10 *Erysiphe* sp. on *Pueraria wallichii*. **a** conidiophore. **b** germ tube. **c** conidium. **d** appressorium. Bar 20 μm

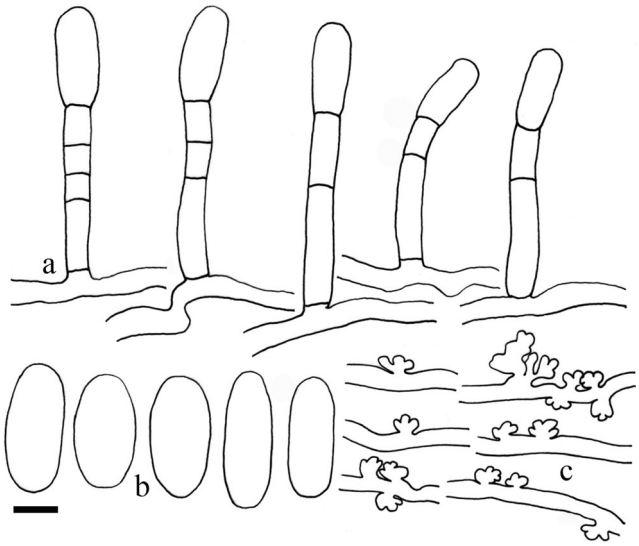

Fig. 11 *Erysiphe* sp. on *Clitoria ternatea*. **a** conidiophores. **b** conidia. **c** appressoria. Bar 20 μm

spp. (Braun and Cook 2012). The present specimen differs from *Ps. clitoriae* (Braun and Cook 2012) by having longer conidiophores, larger foot cells and larger conidia. This is the first report of *Erysiphe* sp. on *Clitoria ternatea* in Thailand.

12. ***Erysiphe* sp. ex *Mucuna bracteata***

Mycelium amphigenous, mainly hypophyllous, white, effuse or in dense patches, persistent or ± evanescent; *hyphae* 3–4.5 μm wide; *hyphal appressoria* lobed, solitary or in opposite pairs; *conidiophores* 70–150 μm long, erect from top of mother cell; *foot cells* 35–76 × 6–10 μm, cylindrical, straight to slender, sometimes flexuous, followed by 1–2 shorter cells, forming conidia singly; *conidia* 30–50 × 13.5–20 μm, ellipsoid-ovoid (Fig. 12).

Material: On *Mucuna bracteata* A.DC. (Fabaceae), THAILAND, Chiang Mai province, Mae Rim, 2 April 2013, J. Meeboon, MUMH6647.

Note: Based on conidiophore morphology and conidial germination patterns, this fungus belongs to the genus *Pseudoidium*, asexual morph of *Erysiphe*. This is the first report of *Erysiphe* on *M. bracteata* in the world.

13. ***Erysiphe baliensis*** Siahaan & S. Takam. **ex *Desmodium triflorum***

Mycelium amphigenous, persistent or evanescent, effuse or in thin, irregular patches; *hyphal cells* 4–7 μm wide; *hyphal appressoria* lobed, solitary, occasionally in opposite pairs; *conidiophores* 65–128 μm long, erect, arising mostly centrally or somewhat laterally from top of mother cell; *foot cells* 18–66 × 6.5–9 μm, cylindrical, straight, curved or somewhat flexuous-sinuous, followed by 0–3 cells, usually shorter, sometimes about as long as the foot cell, forming conidia singly; *conidia* 30–43 × 15–19 μm, ellipsoid-ovoid to doliiform; *germ tubes* ± terminal, short to moderately long, with lobed appressoria (*Pseudoidium* type) (Fig. 13).

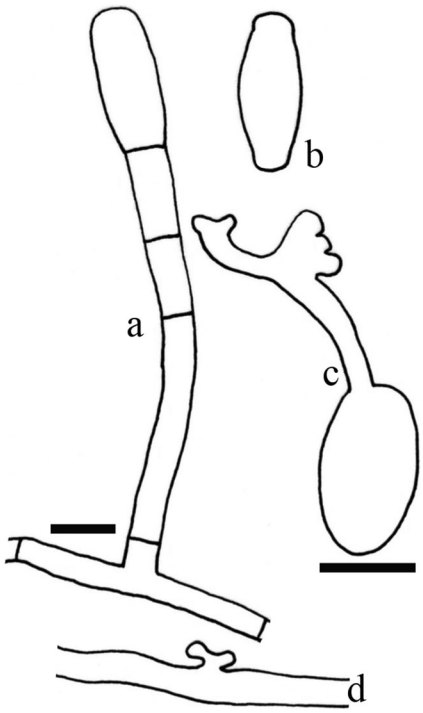

Fig. 12 *Erysiphe* sp. on *Mucuna bracteata*. **a** conidiophore. **b** conidium. **c** germ tube. Bars 20 μm

Material: On *Desmodium triflorum* (L.) DC. (Fabaceae), THAILAND, Chiang Mai province, Mae Rim, 3 April 2013, J. Meeboon, MUMH2605, accession number: LC163916.

Note: *Erysiphe diffusa* (Cooke & Peck) U. Braun & S. Takam., and *E. glycines* F.L. Tai have been known on *Desmodium* (Braun and Cook 2012). The molecular

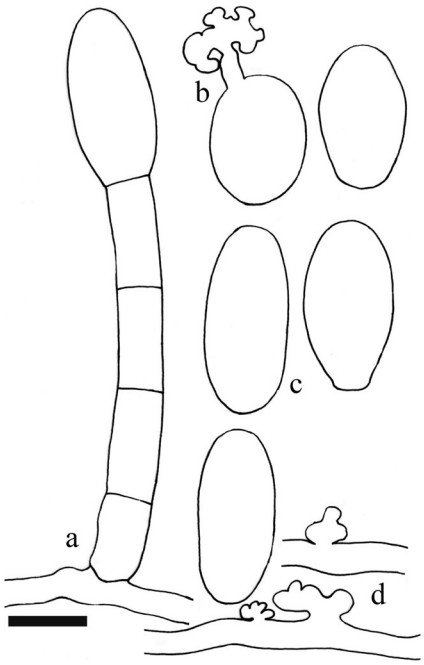

Fig. 13 *Erysiphe* sp. on *Desmodium triflorum*. **a** conidiophore. **b** germ tube. **c** conidia. **d** appressoria. Bar 20 μm

phylogenetic analysis based on ITS sequence data showed that this sequence identical to *E. baliensis* Siahaan & S. Takam. on *Gliricidia sepium* and *Wisteria japonica* (Fig. 19). This is the first report of *E. baliensis* on *D. triflorum* in the world.

Fagaceae

14. ***Erysiphe* sp. ex *Lithocarpus lindleyanus***

Mycelium amphigenous, mainly epiphyllous, persistent to evanescent, effuse or in patches; *hyphae* 3–6 μm wide, thin-walled, smooth, hyaline to yellowish; *hyphal appressoria* lobed; *conidiophores* 70–141 μm long, erect, arising from top of mother cell; *foot cells* 22–55 × 6.5–9 μm, curved, followed by 1–2 shorter cells, forming conidia singly; *conidia* 28–45 × 14–20 μm, ellipsoid or cylindrical (Fig. 14).

Material: THAILAND, Chiang Mai province, Suthep, on *Lithocarpus lindleyanus* (Wall.) A. Camus (Fagaceae), 9 February 2014, J. Meeboon, MUMH3730.

Note: Based on the morphological examination, the current specimen belongs to *Pseudoidium*, asexual morph of *Erysiphe*. *Erysiphe sikkimensis* Chona, J.N. Kapoor & H.S. Gill is the only *Erysiphe* species other than *E*. sect. *Californiomyces* recorded on *Lithocarpus* spp. However, DNA sequencing was failed. This is the first report of *Erysiphe* sp. on *L. lindleyanus* in Thailand.

15. ***Erysiphe* sp. ex *Lithocarpus vestitus***

Mycelium amphigenous, mainly hypophyllous, white, persistent, irregularly effuse, forming patches, sometimes covering the entire surface of the leaves; *hyphal appressoria* lobed to multilobed, solitary or in opposite pairs; *conidiophores* 55–100 μm long, arising from superficial hyphae, terminal on the mother cells; *foot cells* 32–65 × 5–7 μm, short, cylindrical, slightly curved, followed by 1–2 cells, shorter or about as long as the foot cell, forming conidia singly; *conidia* 20–40 × 12–18 μm, ellipsoid-doliiform; *germ tubes* terminal or subterminal, short to moderately long, with lobed appressoria (*Pseudoidium* type) (Fig. 15)

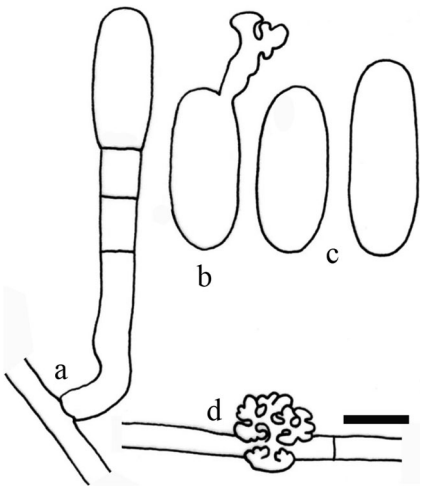

Fig. 14 *Erysiphe* sp. on *Lithocarpus lindleyanus*. **a** conidiophore. **b** germ tube. **c** conidia. Bar 20 μm

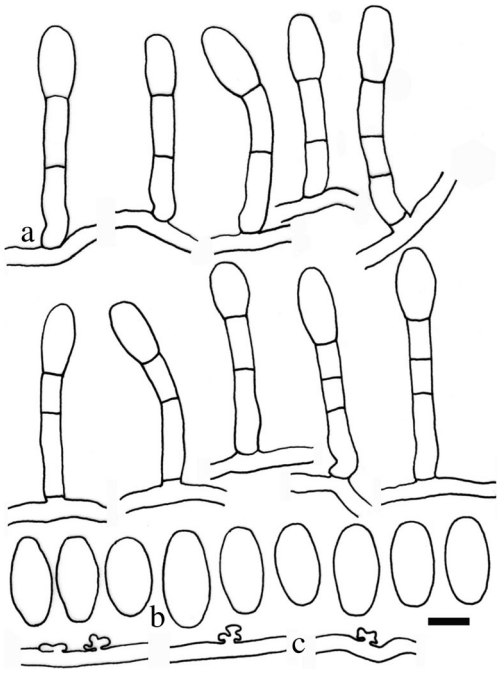

Fig. 15 *Erysiphe* sp. on *Lithocarpus vestitus*. **a** conidiophores. **b** conidia. **c** appressoria. Bar 20 μm

Material: On *Lithocarpus vestitus* (Hickel & A.Camus) Chun (Fagaceae), THAILAND, Chiang Mai province, Suthep, 9 February 2014, J. Meeboon, MUMH4994.

Note: Three species of *Erysiphe* and two species of *Cystotheca* have been reported on *Lithocarpus* (Braun and Cook 2012), but none of them found on *L. vestitus*. The current specimen belongs to *Pseudoidium*, asexual morph of *Erysiphe*. This is the first report of *Erysiphe* on *L. vestitus* in Thailand.

Hydrangeaceae

16. ***Pseudoidium hortensiae*** (Jørst.) U. Braun & R.T.A. Cook **ex *Hydrangea macrophylla***

Mycelium amphigenous, evanescent or almost persistent, effuse, forming thin white and irregular patches; *hyphae* hyaline, branched, septate, hyphal cells 4–5.5 μm wide; *hyphal appressoria* multilobed, 5–25 μm diam., numerous, solitary or often in opposite pairs, sometimes in sequences of up to four pairs per cell; *conidiophores* 40–99 μm long, erect, present on both leaf surfaces, arising ± centrally from the upper surface of mother cells; *foot cells* 27–44 × 7.5–12.5 μm, straight, occasionally slightly curved, cylindrical, usually followed by 1–2 shorter cells or a single longer cell, forming conidia singly, rarely in short false chains; *conidia* 28–42 × 19–23 μm, ellipsoid-ovoid to cylindrical; *germ tubes* at an end, short to moderately long, with lobed appressoria (*Pseudoidium* type) (Fig. 16).

Material: On *Hydrangea macrophylla* (Thunb.) Ser. (Hydrangeaceae), THAILAND, Chiang Mai province, Suthep, 8 January 2007, J. Meeboon, MUMH1832.

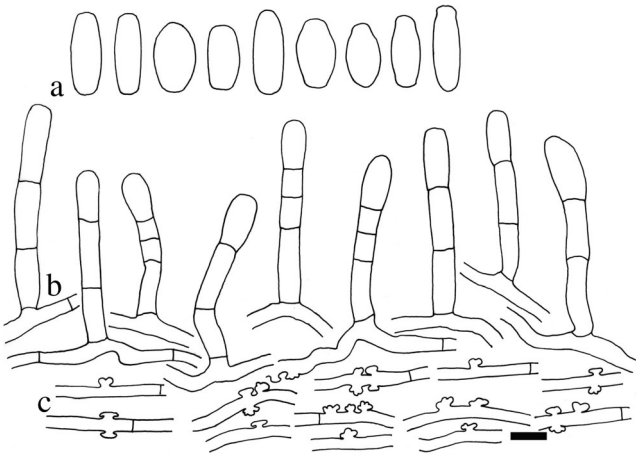

Fig. 16 *Pseudoidium hortensiae* on *Hydrangea macrophylla*. **a** conidiophores. **b** conidia. **c** appressoria. Bar 20 μm

Note: The morphological characteristics of this specimen are identical to *Ps. hortensiae* (Braun and Cook 2012). This is the first report of *Ps. hortensiae* on *Hydrangea macrophylla* in Thailand.

Lamiaceae

17. ***Erysiphe* sp. ex *Microtoena insuavis***

Mycelium amphigenous, white, effuse or in patches, persistent; *hyphae* 3.5–7.5 μm wide, branched, septate; *hyphal appressoria* nipple-shaped to moderately lobed, mostly solitary; *conidiophores* 40–70 μm long, erect, arising from the upper surface of mother cells; *foot cells* 12–30 × 10–12.5 μm, cylindrical, straight, followed by 0–1 shorter cells, by a longer cell or by a cell of about the same length, forming conidia singly; *conidia* 25–38.5 × 19.5–22.5 μm, ovoid-doliiform to subcylindrical; *germ tubes* ± terminal, with lobed appressoria (*Pseudoidium* type) (Fig. 17).

Material: On *Microtoena insuavis* (Hance) Prain ex Briq. (Lamiaceae), THAILAND, Chiang Mai province, Suthep, 8 January 2007, J. Meeboon, MUMH1757.

Note: Powdery mildews have been recorded on numerous species of Lamiaceae, but not on *M. insuavis*. This study is the first record of powdery mildew on *M. insuavis* in the world. *Microtoena* is distributed in the area from the Himalaya Mountains to Western China, and it is also found in northern Thailand. Based on conidiophore morphology and conidial germination patterns, this fungus belongs to the genus *Pseudoidium*, asexual morph of *Erysiphe*.

18. ***Erysiphe* sp. ex *Ocimum sanctum***

Mycelium amphigenous, effuse, evanescent, occasionally ± persistent; *hyphae* 4–7 μm wide; *hyphal appressoria* lobed, solitary or in opposite pairs; *conidiophores* 72–110 μm long, erect, on top of mother cell; *foot cells* 23–55 × 7–10 μm, straight or slightly curved, cylindrical, followed by 1–2 mostly shorter cells, with a basal septum at the branching point of the mycelium, forming conidia singly; *conidia* 28–36 × 8–22 μm, ellipsoid-ovoid to cylindrical; *germ tubes* short to moderately long, with lobed appressoria (*Pseudoidium* type) (Fig. 18 and 19).

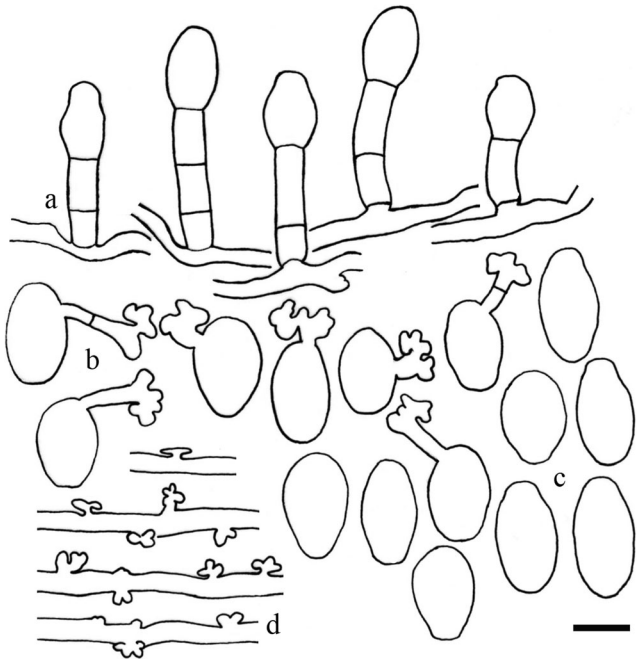

Fig. 17 *Erysiphe* sp. on *Microtoena insuavis*. **a** conidiophores. **b** germ tubes. **c** conidia. **d** appressoria. Bar 20 μm

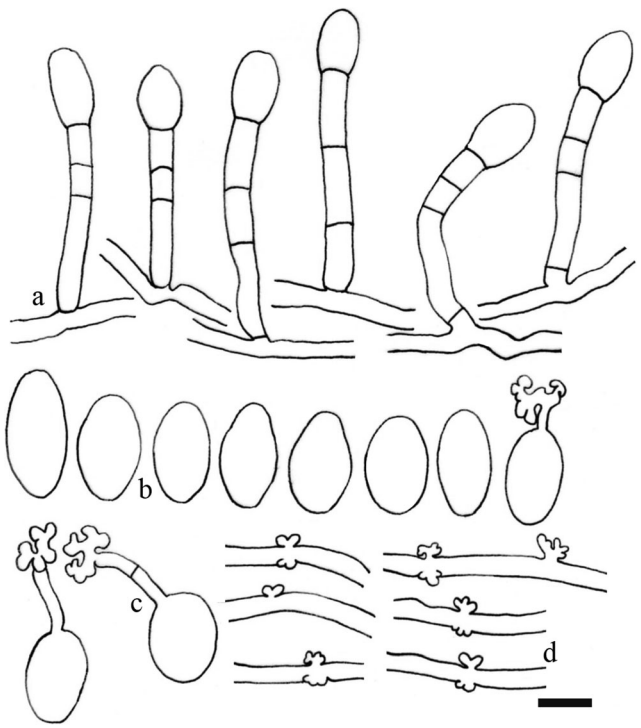

Fig. 18 *Erysiphe* sp. on *Ocimum sanctum*. **a** conidiophores. **b** conidia. **c** germ tubes. **d** appressoria. Bar 20 μm

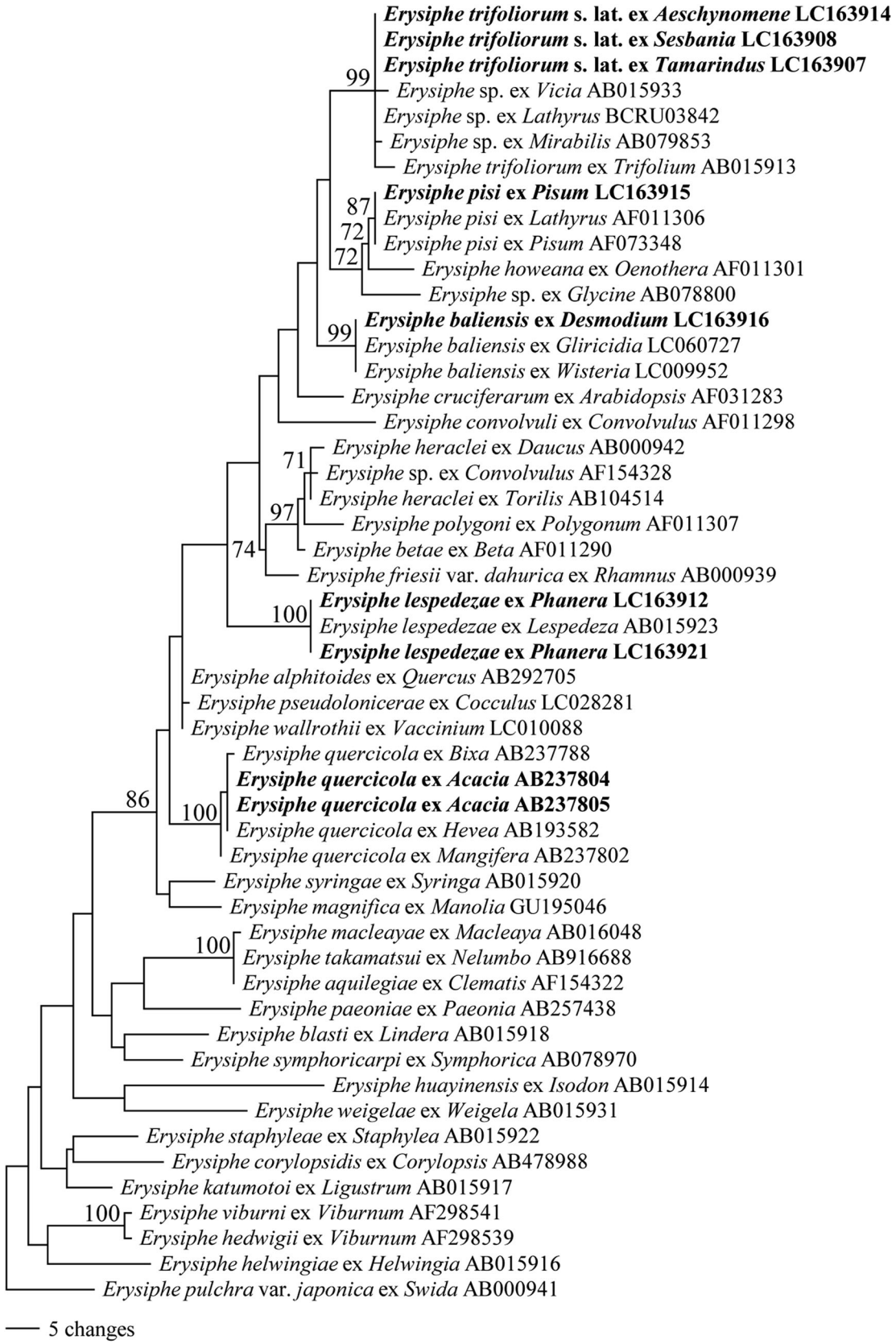

Fig. 19 One of the most parsimonious trees reconstructed by analysis of ITS sequence data of *Erysiphe* (*Microsphaera* lineage). BS (>70%) values were shown on the respective branch. Sequences from the collections reported in this study are shown in boldface

Material: On *Ocimum sanctum* L. (Lamiaceae), THAILAND, Chiang Rai province, 8 December 2013, J. Meeboon, MUMH3753.

Note: This is the first study of *Pseudoidium* on *Ocimum sanctum* in Thailand. In Braun and Cook (2012), *Oidium ocimi-sancti* Puzari, A.K. Sarbhoy, N. Ahmad & D.K. Argawal is the only powdery mildew species found on *Ocimum sanctum*. However, the status of this species is unclear (Braun and Cook 2012). Further analysis is necessary to determine the identity of this specimen.

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References

Amano (Hirata) K (1986) Host Range and Geographical Distribution of the Powdery Mildew Fungi. J Sci Soc Press, Tokyo

Braun U (1982) Morphological studies in the genus *Oidium* (III). Zentralblatt für Mikrobiologie 137:314–324

Braun U (1987) A monograph of the Erysiphales (powdery mildews). Beihefte zur Nova Hedwigia 89:1–700

Braun U, Cook RTA (2012) Taxonomic manual of the *Erysiphales* (powdery mildews). CBS Biodivers. Ser. No. 11. CBS–KNAW Fungal Biodivers. Centre, Utrecht

Divarangkoon R, Meeboon J, Monkhung S, To-anun C, Takamatsu S (2011) Two new species of *Erysiphe* (*Erysiphales*, *Ascomycota*) from Thailand. Mycosphere 2:231–238

Edgar RC (2004) MUSCLE: a multiple sequence alignment method with reduced time and space complexity. BMC Bioinf 5:113

Falloon RB, Sutherland PW, Hallett IC (1989) Water, fungicides and host resistance affect development of Erysiphe pisi on pea leaves; an electron microscope study. Agron. Soc. of N. Z., Proc. of the National Symp. and Workshop on Grain Legumes held at Lincoln College, December 11–12, p. 121

Farr DF, Rossman AY (2016) Fungal Databases, Syst. Mycol. and Microbiol. Lab., ARS, USDA. Available at: http://nt.ars-grin.gov/fungaldatabases/. Accessed on 3 June 2016

Hidayat I, Meeboon J, Takamatsu S (2014) First report of *Pseudoidium* aff. *neolycopersici* in Indonesia. Australas Plant Pathol Soc 9:1–3

Hirata T, Takamatsu S (1996) Nucleotide diversity of rDNA internal transcribed spacers extracted from conidia and cleistothecia of several powdery mildew fungi. Mycoscience 37:283–288

Meeboon J, Takamatsu S (2015) *Erysiphe takamatsui*, a powdery mildew of lotus: rediscovery of teleomorph after 40 years, morphology and phylogeny. Mycoscience 56:159–167

Meeboon J, Takamatsu S (2016) Notes on powdery mildews (Erysiphales) in Thailand II. *Erysiphe*. Trop. Plant. Pathol. 41: 357–369

Meeboon J, Hidayat I, Kramadibrata K, Nurcahyanto D, Siahaan SAS, Takamatsu S (2012a) *Cystotheca tjibodensis* (Erysiphaceae, Ascomycota): rediscovery in Java after 90 years and first finding of anamorph. Mycoscience 53:386–390

Meeboon J, Hidayat I, Takamatsu S (2012b) *Erysiphe javanica* sp. nov., a new tropical powdery mildew from Indonesia. Mycotaxon 120: 189–194

Meeboon J, Hidayat I, Takamatsu S (2012c) *Pseudoidium javanicum*, a new species of powdery mildew on *Acalypha* spp. from Indonesia. Mycoscience 54:183–187

Meeboon J, Hidayat I, Takamatsu S (2012d) *Setoidium castanopsidis*, a new species of anamorphic *Cystotheca* (Ascomycota, Erysiphales) from Indonesia. Mycoscience 54:274–278

Meeboon J, Divarangkoon R, Takamatsu S (2013) Two new species of *Erysiphe* sect. *Uncinula* (*Erysiphales*): *Erysiphe fernandoae* and *E. michikoae*. Mycoscience 54:2–7

Meeboon J, Hidayat I, Takamatsu S (2016) Notes on powdery mildews (Erysiphales) in Thailand I. *Podosphaera sect. Sphaerotheca*. Plant Pathol Quar 6:142–174

Monkhung S, To-anun C, Takamatsu S (2011) Molecular approach to clarify taxonomy of powdery mildew on Chilli plants caused by *Oidiopsis sicula* in Thailand. J Agric Technol 7:1801–1808

Monkhung S, To-anun C, Takamatsu S (2013) Molecular and morphological characterization of *Phyllactinia cassiae-fistula*e (Erysiphaceae; Ascomycota) from Thailand. Afr J Biotechnol 12:109–114

Shin HD (1988) Erysiphaceae of Korea. Thesis, Dept. of Agric. Biol., Graduate Sch. of Seoul National Univ

Shin HD (2000) Erysiphaceae of Korea. National Inst. of Agric. Sci. and Technol. Suwon, Korea

Shin HD, La YJ (1993) Morphology of edge lines of chained immature conidia on conidiophores in powdery mildew fungi and their taxonomic significance. Mycotaxon 66:445–451

Siahaan SAS, Hidayat I, Kramadibrata K, Meeboon J, Takamatsu S (2015) *Phyllactinia poinsettiae* sp. nov.: a new species of powdery mildew on poinsettia from Indonesia. Mycoscience 56:580–583

Siahaan SAS, Kramadibrata K, Hidayat I, Meeboon J, Takamatsu S (2016a) *Erysiphe baliensis* and *E. sidae*, two new species of anamorphic *Erysiphe* (powdery mildew) from Indonesia. Mycoscience 57:35–41

Siahaan SAS, Kramadibrata K, Hidayat I, Meeboon J, Takamatsu S (2016b) *Bauhinia purpurea*, *Durio zibethinus*, and *Nephelium lappaceum*: additional hosts of the asexual morph of *Erysiphe quercicola*. Mycoscience 57:375–383

Swofford DL (2002) PAUP*: phylogenetic analysis using parsimony (*and other methods), version 4.0b10. Sinauer, Sunderland, MA.

Takamatsu S, Kano Y (2001) PCR primers useful for nucleotide sequences of rDNA of the powdery mildew fungi. Mycoscience 42: 135–139

Takamatsu S, Ito H, Shiroya Y, Kiss L, Heluta V (2015) First comprehensive phylogenetic analysis of the genus *Erysiphe* (Erysiphales, Erysiphaceae) I. The Microsphaera lineage. Mycologia 107:475–489

Tamura K, Stecher G, Peterson D, Filipski A, Kumar S (2013) MEGA6: Molecular Evolutionary Genetics Analysis Version 6.0. Mol Biol Evol 30:2725–2729

To–anun C, Limkaisang S, Fangfuk W, Sato Y, Braun U, Takamatsu S (2003) A new species of *Brasiliomyces* (*Erysiphaceae*) on *Dalbergia cultrata* var. *cultrata* from Thailand. Mycoscience 44:447–451

To–anun C, Kom–un S, Sunawan A, Fangfuk W, Sato Y, Takamatsu S (2005) A new subgenus, *Microidium*, of *Oidium* (*Erysiphaceae*) on *Phyllanthus* spp. Mycoscience 46:1–8

Walsh SP, Metzger DA, Higuchi R (1991) Chelex 100 as a medium for simple extraction of DNA for PCR–based typing from forensic material. Biotechniques 10:506–513

White TJ, Bruns TD, Lee S, Taylor J (1990) Amplification and direct sequencing of fungal ribosomal genes for phylogenetics. In: Innis MA, Gelfand DH, Sninsky JJ, White TJ (eds) PCR protocols: a guide to methods and applications. Acad. Press, San Diego, pp 315–322