First record of *Podosphaera xanthii* on *Peperomia tetragona*

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Received: 5 May 2017 / Accepted: 14 July 2017 / Published online: 24 July 2017
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Abstract In January 2017, *Peperomia tetragona* was found to be infected with a powdery mildew in Korea. No chasmothecia were observed. The fungus associated with foliar signs of powdery mildew was identified as *Podosphaera xanthii* using morphological characteristics of the anamorph and molecular analysis of ITS regions. This is the first report of powdery mildew infections on *P. tetragona* worldwide.

Keywords *Erysiphaceae* · Identification · Parallel peperomia · *Peperomia puteolata* · *Piperaceae*

In early February 2017, two plants of *Peperomia tetragona* (syn. *P. puteolata*), known as parallel peperomia, exhibiting signs of powdery mildew were sent from a hobby florist to H.D. Shin of Korea University for diagnosis. The peperomia plants were known to be pot-grown from April 2016 in the greenhouse and cared for in an indoor facility from October 2016 for ornamental purpose. Early signs of powdery mildew started as thin white colonies on both sides of young leaves and occasionally on tender stems from early January 2017. The infections were usually severe on young leaves (Fig. 1a, b), causing discolouration and premature defoliation and thus markedly detracting from

the aesthetic value of the plant. A voucher specimen was deposited in the Korea University Herbarium (KUS-F29727).

To identify the powdery mildew associated with the infections, a fresh specimen was mounted in water in preparation for microscopic analysis. The morphological characteristics of the fungal structures were examined using bright-field and differential-interference contrast microscopy using an Olympus BX51 microscope (Olympus, Tokyo, Japan) for measurements, and with a Zeiss AX10 microscope equipped with an AxioCam MRc5 camera (Carl Zeiss, Göttingen, Germany) for photographs. At least 30 measurements were taken of each structure. Hyphae were sub-straight to flexuous, branched, and 4–7 µm in diameter. Hyphal appressoria were nipple-shaped or nearly absent. Conidiophores arising from the upper part of running hyphae were erect, 140–230 × 10–12 µm and produced 2 to 5 immature conidia in chains with a crenate outline (Fig. 1c). Foot-cells of conidiophores were straight, cylindric, and 50–80 µm long. Conidia were hyaline, ellipsoid-ovoid to barrel-shaped, 25–35 × 16–22 µm with a length/width ratio of 1.2–1.9, and contained distinct fibrosin bodies (Fig. 1d). Simple germ tubes were produced from the lateral position of conidia (Fig. 1e, f). No chasmothecia were observed until the leaves senesced and dropped. These structures are typical of the powdery mildew *Euoidium* anamorph of the genus *Podosphaera*. The specific measurements and morphological characteristics were consistent with those of *P. xanthii* (Braun and Cook 2012).

To confirm the initial identification, the internal transcribed spacer (ITS) regions of KUS-F29727 were amplified with primers ITS5/P3 as described in Takamatsu et al. (2009), and sequenced directly. The resulting 688 bp sequence was deposited in GenBank (Accession No. MF043939). A NCBI BLAST search of the Korean isolate showed 99% similarity with the sequences of *P. xanthii*

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Fig. 1 Powdery mildew of *Peperomia tetragona* by *Podosphaera xanthii*. **a** Symptoms on leaves. **b** Close-up view of symptoms. **c** Conidiophore. **d** Conidia. **e** Conidia in germination

isolates of various host genera (e.g., KJ698669, KP120971, KP120972, etc.). A phylogenetic tree was constructed with the ITS sequence generated in this study and 17 sequences of *Podosphaera* species retrieved from GenBank, using the Maximum Likelihood (ML) method

in MEGA7 (Kumar et al. 2016). In a ML tree (Fig. 2), the Korean isolate on *P. tetragona* was clustered into a clade that contained *P. xanthii* from several hosts, as supported by Takamatsu et al. (2010). Thus, both the morphological characteristics and phylogenetic analysis support the identification of the newly collected powdery mildew fungus on *P. tetragona* as *P. xanthii*.

Pathogenicity was confirmed through inoculation tests by gently pressing a diseased leaf onto young leaves of three asymptomatic, potted plants. Three non-inoculated plants were used as controls. Plants were maintained in a greenhouse at 24–30 °C. Inoculated leaves developed signs of powdery mildew after 9 days, whereas the control plants remained symptomless. The fungus present on the inoculated leaves was morphologically identical to that observed on the original infected leaves. The pathogenicity tests were performed twice with similar results.

The genus *Peperomia* accommodates as many as 1600 species spread in the tropical and subtropical regions of the world, though concentrated in Central America and northern South America (Mathieu and Posada 2006; Frenze et al. 2015; Gutierrez et al. 2016). Numerous horticultural varieties have been commercialized and cultivated worldwide (<http://www.peperomia.net/horticulture.asp>). Nevertheless, occurrence of powdery mildews on *Peperomia* spp. seems to be rare. The only record was in Denmark as *Oidium piperis* on *Peperomia verticillata* (Amano 1986). According to USDA-ARS database (Farr and Rossman 2017), *Oidium piperis* has also been recorded on *Piper betle* from Asia (India, Myanmar, Sri Lanka, and Taiwan) and also on *P. aduncum* in Brazil. Braun and Cook (2012) supposed *O. piperis* to be a species of *Podosphaera* based on previous record of *Sphaerotheca fuliginea* s. lat. (now mostly belonging to *Podosphaera xanthii*) in Taiwan. *Oidium piperis* on *P. aduncum* in Brazil (Soares and Barreto 2005), however, does not belong to

Fig. 2 Phylogenetic relationship between *Podosphaera xanthii* isolates and some reference isolates retrieved from NCBI, inferred by the Maximum Likelihood method using the ITS regions. Bootstrap values ($\geq 70\%$) based on 1000 replications are indicated above the branches. The scale bar represents 0.02 nucleotide substitutions per site. The isolate used in this work is indicated in bold

Podosphaera, since the conidia do not contain fibrosin bodies (Braun and Cook 2012). Nevertheless, there has been no molecular data for any specimens of powdery mildews on *Peperomia* and *Piper* plants. The current work provides the first ITS sequence data and proves the identity of a *Podosphaera* powdery mildew occurring on a piperaceous plant.

To our knowledge, this is the first report of powdery mildew caused by *P. xanthii* on *P. tetragona* globally. In commercial production of *P. tetragona* cuttings in plastic greenhouses, damages caused by an unidentified powdery mildew were found in May 2005 (data unpublished, samples not preserved, the fungus not identified, but several photos showing typical powdery mildew signs preserved by K.S. Han). Therefore, constant attention should be paid to powdery mildews during peperomia production.

Acknowledgements This work was supported by the BK21 Plus program 2016–2020, funded by the National Research Foundation of Korea. Additional funding was provided through a grant from Korea University to HDS.

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