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The first appearance of the citrus flower moth (*Prays citri* (Millière, 1873)) (Lepidoptera: Praydidae) in Lithuania

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Abstract

The citrus flower moth (*Prays citri* (Millière, 1873)) feeding on calamondin (*Citrus* × *macrocarpa*) in greenhouses in Lithuania were found on 20 April 2021. Based on a comprehensive analysis of morphological features of the moths, they were identified as *Prays citri* (Millière, 1873) (Lepidoptera: Praydidae). A small population of moths successfully survived in the unheated greenhouse till November. This species is one of the most harmful pests of citrus plants and can cause substantial economic losses in the Mediterranean basin and some tropical areas of the world. However, it has been detected in some central and even northern European countries in the last two decades. The article provides information about the first appearance of *P. citri* in Lithuania. Additionally, the paper includes a detailed and originally illustrated morphological description based on the collected specimens and a brief review of species distribution, biology, and the possible risk of this pest spreading in the country.

Keywords: moth, citrus pest, calamondin.

Introduction

Several alien insect species have been discovered in Lithuania in the last few decades. The invasions of some of them are regarded as associated with climate change or natural colonization (Nagrodskaitė et al., 2011; Karalius, Karaliūtė, 2019), while others were introduced with exotic plants by humans (Malumphy et al., 2008). The expansion of some species of exotic lepidopterans, such as *Plodia interpunctella* (Hübner, 1813), *Cameraria ohridella* Deschka & Dimic, 1986, and *Cydalima perspectalis* (Walker, 1859) was not only successful; in addition, these species have become among of the most dangerous pests in Lithuania (Ivinskis et al., 2009; Paulavičiūtė, 2021).

Praydidae is a relatively young family of Lepidoptera placed in the superfamily Yponomeutoidea (Mutanen et al., 2010). At present, it comprises at least 67 described species in the world (Lewis, Sohn, 2015; Cong, Li, 2017; Liu, Yan, 2017; Sohn, Epstein, 2019; Bippus, 2020). Till now, only three species belonging to two genera of Praydidae were found and registered in Lithuania: *Atemelia torquatella* (Lienig & Zeller, 1846), *Prays fraxinella* (Bjerkander, 1784), and *P. ruficeps* (Heinemann, 1854) (Ivinskis, Rimšaitė, 2018). All three species are widely distributed in Northern Europe and develop on naturally growing plants (Aarvik et al., 2017). The species of the genus *Prays* is not easily distinguished, e.g., *P. ruficeps* can be separated from *P. fraxinella* only by DNA barcodes (Aarvik et al., 2017). Two of them, the olive moth *P. oleae* (Bernard, 1788) and the citrus flower moth *P. citri* (Millière, 1873) can cause substantial economic losses in agriculture in the Mediterranean Basin (Carter, 1984). The latter demonstrates the possibility to spread and survive in greenhouses in some Central and even Northern European countries (Huemer, Hebert, 2016; Takács et al., 2018; Buhl et al., 2019; Mey, 2020; CABI, 2021; Gustafsson, Malm, 2021). Early detection and reliable identification of potential pests is one of key steps in preventing their population outbreaks and enormous harm.

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The aims of this study were to analyse and clearly illustrate those morphological features that can be used to distinguish the *P. citri* found feeding on calamondin (*Citrus* × *macrocarpa*) in greenhouses of Lithuania and to review its distribution, biology, and the possible risk of the spread of this pest in the country.

Materials and methods

The cultivar 'Oriana' calamondin (*Citrus* × *macrocarpa*) plants were imported to Lithuania (Šilutė and Kaunas districts) from Portugal on 20 April 2021 with the aim to investigate the suitability for indoor cultivation of *Citrus* spp. Few specimens of moths were observed on the plants during the potting up. As the moths were observed continuously, sticky yellow insect traps were introduced for its control and monitoring. More than 50 specimens of moths were trapped in the greenhouse containing several hundreds of plants by 1 June. Five sticky yellow insect traps were used from 22 April to 1 June 2021. They were evenly spaced close to the plants in the greenhouse. After analysis of morphological features and following the pictures and descriptions presented by Moth Photographers Group (2019), Lepiforum (2020), Mey (2020) and Wheeler et al. (2021), they were identified as *Prays citri* (Milliére, 1873). For monitoring of moths, some of the infested calamondin plants were taken to the greenhouse of the Botanical Garden of Vytautas Magnus University, while the rest were treated by insecticides, as their caterpillars threatened to harm the plants.

The moth population was monitored only by visual inspection of plants on a weekly basis from 15 June to 1 of November 2021 in the greenhouse of the Botanical Garden of Vytautas Magnus University. At least 50 specimens of *P. citri* were examined; four males and four females were dissected for analysis of genital structures. Adult specimens were examined externally using stereomicroscopes MBS-10 (Lytkarino Optical Glass Plant, Russia) and Euromex Stereo Blue (Euromex, The Netherlands). The forewing length was measured along the costa from wing base to the apex of the terminal fringe scales. For the wingspan, the forewing length was doubled, and thorax width added.

Genitalia were prepared following the standard method described by Robinson (1976). Before permanent slide-mounting in Euparal mounting resin, the genitalia were studied, and some morphological structures were photographed in glycerol. The male genital capsule was stained with fuchsin and female genitalia with chlorazol black Direct Black 38/Azo Black (Alfa Aesar GmbH & Co KG, Germany). Genital morphology was examined using microscope a Novex B (Euromex, The Netherlands). The photographs of adults were taken using a stereomicroscope Euromex Stereo Blue and a digital camera E3ISPM12000KPA (Koritcam, China). The photographs of genitalia were made using a microscope Novex B and a digital camera E3ISPM12000KPA. The descriptive terminology of morphological structures follows Klots (1970) and Cong and Li (2017).

The examined material is stored in the collection of Kaunas Tadas Ivanauskas Zoological Museum, Lithuania.

Results and discussion

Analysis of distinguishable morphology of Prays citri. One species belonging to the genus *Prays* (50 specimens) was first identified on calamondin plants from the greenhouses in Šilutė and Kaunas districts. Based on morphological characteristics, this species was identified as *P. citri*. The species of this genus are characterised by the lack of a pecten on the antennal scape (Figure B), the absence of the medial process on the eight tergite of the male, and the presence of the saccular process in male genitalia and rudimentary uncus (Sohn, Wu, 2011; Cong, Li, 2017). An illustrated account of the morphology of the genus *Prays* was presented by Cong and Li (2017). The identification of the species within the genus using the external characters is quite limited: only some species can be distinguished by their size, wing shape and pattern (Sohn, Wu, 2011). However, examination of genital structures is needed for the correct identification of most species, including *P. citri* (Mey, 2020).

Description of the imago male (Figure A). Head: frons and vertex smooth, whitish grey, sparsely intermixed with grey brown tipped scales; labial palpus drooping, almost straight, about 1.5 times as long as width of head, whitish grey above, grey brown below; scape whitish grey, with few grey brown scales above, without pecten; flagellum with very short visible cilia about one-fifth diameter of shaft, blackish brown, weakly annulated with paler rings. Thorax and tegulae covered by whitish grey scales with greyish brown tips. Forewing length 5.2–6.2 mm; wingspan 11.5–14.6 mm; greyish brown, strongly mottled by dark tipped scales, with several irregular blackish brown stripes distally, mixed with white scales; costal margin with few ill-defined blackish brown strigulae alternated with whitish grey on basal half; wide white fascia extending obliquely inwards from distal one-fifth of the costal margin to beyond tornus, its posterior half with a transverse greyish brown band close to outer margin; large irregular black speckle at middle of forewing, posteriorly meeting blackish brown strigulae from dorsum; two blackish brown marks located before blackish brown apex, dorsum with few irregular blackish brown strigulae alternated with whitish grey; fringe scales greyish brown. Hindwing brownish grey, with fringe concolorous. Female similar to male, but somewhat lighter (Figure B).

Male genitalia (Figures C–G). Uncus rudimentary as a shallow protuberance on posterior margin of tegumen. Socius short, triangularly-shaped (Figure F), bearing long setae, 1.5 times as long as wide at base, evenly tapering to a pointed apex. Tegumen trapezoidal, extended medially for about one-third of the length of lateral band, anterior margin concave. Tuba analis with slender subscaphium, its anterior margin fused with posterior margin of gnathos. Gnathos band-like, its posterior margin protruded to a shallow triangular process. Valva narrow, separated from sacculus at base, covered with dense long setae, costa almost straight, ventral margin slightly broadened at two-thirds from base, apex narrowed and slightly curved dorsad; sacculus almost as long as valva, broadest at base, dorsal margin arched, ventral margin concave medially, covered with dense long setae and with a tuft of strong setae at apex, distally sacculus produced to a long, acute thorn. Anellus lobes with long setae; dorsal margin of anellus reinforced, with broad, tongue-shaped process on ventral margin, distally fused to gnathos. Vinculum broad V-shaped; saccus expanded distally, rounded apically. Phallus slender, about two times as long as valva, slightly thickened basally, curved medially; vesica with two long cornuti and row of minute spines.

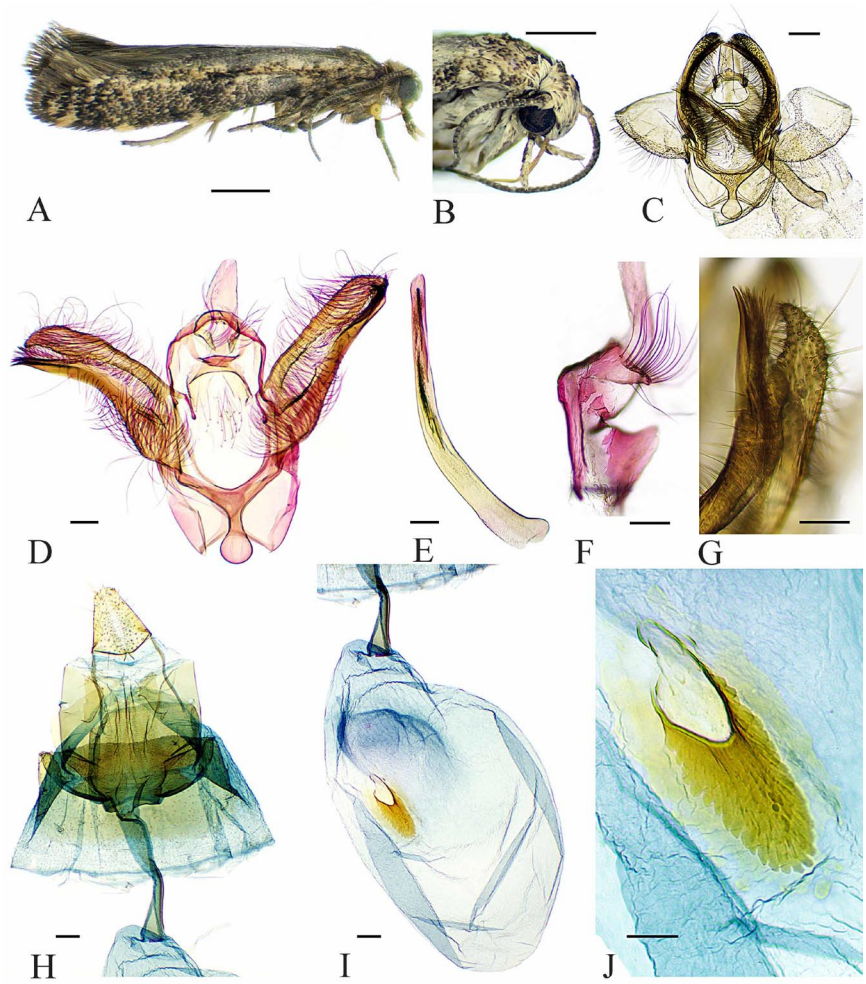

Figure. Morphological features of the adults of *Prays citri*: A – habitus (male, lateral view; scale bar 10 mm), B – frontal part of habitus (female, lateral view; scale bar 5 mm); C–G – male genitalia, C – general view and pleural lobes of VIII segment of the abdomen (scale bar 0.2 mm), D – general view (flattened), phallus removed, E – phallus, F – lateral view of socius, G – sacculus (left) and apical part of valva (right); H–J – female genitalia, H – general view of caudal part, I – ductus bursae and corpus bursae, J – signum (scale bars for C–J = 0.1 mm)

Female genitalia (Figures H–J). Papilla analis longer than wide, covered by short setae. Apophysis posterioris 3.2 times as long as apophysis anterioris. Lamella postvaginalis produced into a pair of thick finger-like processes, with sparse long setae. Sternum VIII with longitudinal central groove covered by minute spines. Ostium bursae open on anterior margin of sternum VIII. Antrum short, cup-like, widened posteriorly. Ductus bursae about two times as long as papilla analis. Corpus bursae oviform, more than two times longer than ductus bursae; signum elliptical, concave elliptically in posterior half, dentate along margins, placed medially.

Male and female genitalia were examined with emphasis on diagnostic characters, and our specimens were compared with the previously published images of *P. citri* (Moth Photographers Group, 2019; Lepiforum, 2020; Mey, 2020; Wheeler et al., 2021). This comparison revealed that some morphological traits are not clearly visible in these illustrations, e.g., shape of socius (especially lateral view), apex of sacculus, gnathos connection with subscaphium and anellus, and the shape of cornuti. It is also worthy of notice that signum is slightly variable in shape.

The detailed description of genitalia provided here will hopefully expand our knowledge about species morphology. It also can be useful for correct identification, which is of fundamental importance in order to provide correct information on species distribution and biology in the future.

A brief review of the geographic distribution of P. citri. The moths reared from the caterpillars collected from the *Citrus medica* L. (cedratier) in Corsica island were described as *Acrolepia citri* by Pierre Millière (1873). Later Rebel (1906) suggested to move this species to the genus *Prays*. Currently, *P. citri* is widespread in the Mediterranean region and has been introduced in some countries of southern Africa (CABI, 2021). With citrus plants seedlings, the species was spread in Madeira and the Azores archipelagos (Carvalho et al., 1996). *Citrus* species are native to the subtropical and tropical regions of Asia, islands of south-eastern Asia near Oceania and north-eastern Australia (Vu et al., 2018), but the distribution range of this species is probably much wider than considered by Lewis and Sohn (2015). However, some authors consider the distribution of another species associated with citrus plants in these regions: *Prays endocarpa* Meyrick, 1919; *P. endolemma* Diakonoff, 1967 and *P. nephelomima* Meyrick, 1907 (Robinson et al., 1994; CABI, 2021). With imported citrus plants, *P. citri* has also been introduced in some countries of central and northern Europe, such as Austria (Huemer, Hebert, 2016), Hungary (Takács et al., 2018), Germany (Mey, 2020), the

Netherlands (Zwier, 2018), the United Kingdom (British Microlepidoptera, 2001), Denmark (Buhl et al., 2019), and Norway (Gustafsson, Malm, 2021), where it survives in greenhouses.

Our discovery of this species is the first in the eastern Baltic region. Citrus plants are popular in Lithuania and are cultivated for decorative and medical purposes in greenhouses, orangeries or indoors (Stanienė, Stanys, 2017). Every year large numbers of various species and hybrids of genus *Citrus* are imported from tropical regions to the country. However, *P. citri* was first detected only in 2021, although it cannot be ruled out that this pest has been introduced in the territory of Lithuania in the same way before. The risk of this pest spreading in the wild is very low due to the absence of its host plants; however, the chances of its survival inside (e.g., in greenhouses) are quite high. This risk may be exacerbated in particular by the warming of the climate and the popularity of cultivation of exotic plants in greenhouses in Lithuania. Also, it is worthy to note that *P. citri* was observed to feed on calamandin (*Citrus* × *microcarpa*), which is not mentioned among major host plants for this species (EPPO; https://gd.eppo.int).

A brief review of the life cycle of P. citri. *P. citri* is oligophagous on various *Citrus* species and hybrids (Rutaceae), although it demonstrates a preference for lemon (*Citrus limon* (L.), key lime (*C.* × *aurantifolia* Swingle), pummelo (*C. decumana* L.), mandarin orange/tangerine (*C. reticulata* Blanco), orange (*C.* × *sinensis* (Osbeck)), and grapefruit (*C.* × *paradisi* Macfad.) (Ibrahim, Shahateh, 1984; Abd El-Kareim et al., 2017). Occasionally this moth can also attack *Casimiroa edulis* La Llave & Lex. and *Ligustrum lucidum* W. T. Aiton (Olivaceae) (Sinacori, Mineo, 1997), or *Manilkara zapota* (L.) van Royen (Sapotaceae) (Martinez et al., 2019). The larvae feed both internally and externally on flowers, flower buds, and small fruits (Carimi et al., 2000); they can also feed on leaves (Ibrahim, Shahateh, 1984). The duration of the life cycle is highly depending on temperature and can lasts 17–25 days in most appropriate (at 25–30°C) conditions (Ibrahim, Shahateh, 1984; Carimi et al., 2000). In the wild, moths can complete at least three annual generations in Greece (Karamaouna et al., 2009) and up to 11 generations in Egypt (Badr et al., 2018). The larvae of *P. citri* cease to feed and develop at the temperature of 10°C (CABI, 2021). Depending on the climate, they can overwinter in the pupal stage in silky cocoons or in the larval stage, or, finally, as eggs or adults (Bissanti, 2021).

During the current study, the moths survived successfully in the unheated greenhouse till November in small population (during the vegetation period, the rapid increase in the number of individuals was not detected). A fully grown larvae and cocoons were observed on 20 September.

It would be interesting to determine the ability of this moth to survive in unheated greenhouses during winter. Therefore, further research into biology of this pest in Lithuania should be continued.

Conclusions

1. The moths found feeding on calamondin (*Citrus* × *macrocarpa*) in greenhouses in Lithuania were identified as citrus flower moths (*Prays citri* (Millière, 1873)) (Lepidoptera: Praydidae).

2. The detailed description of genitalia of *P. citri* provided in this paper will hopefully expand the knowledge about the morphology and trustworthy identification of the species.

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Pirmasis citrusinės žiedų kandies (*Prays citri* (Millière, 1873)) (Lepidoptera: Praydidae) aptikimas Lietuvoje

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Santrauka

Lietuvos šiltnamiuose 2021 m. balandžio 20 d. buvo aptikti drugiai ir drugių vikšrai, mintantys kalamondinais (*Citrus* × *macrocarpa*). Po išsamios drugių morfologinių požymių analizės nustatyta, kad jie priklauso *Prays citri* (Millière, 1873) (Lepidoptera: Praydidae) rūšiai. Šie drugiai negausiomis populiacijomis sėkmingai vystėsi iki 2021 m. lapkričio mėnesio. Tai vienas žalingiausių citrusinių augalų kenkėjų, galintis padaryti reikšmingų ekonominių nuostolių Vidužemio jūros regione ir kai kuriose atogrąžų vietovėse. Ši rūšis per pastaruosius porą dešimtmečių išplito į kai kurias Vidurio ir Šiaurės Europos šalis. Straipsnyje pateikta informacija apie pirmąjį šios rūšies aptikimą Lietuvoje. Ištyrus šalyje aptiktus individus pateiktas išsamus ir originaliomis nuotraukomis iliustruotas suaugusių drugių morfologijos aprašas, trumpa šios rūšies paplitimo, biologijos ir galimo išplitimo Lietuvoje apžvalga.

Reikšminiai žodžiai: kandis, citrusų kenkėjas, kalamondinas.