RAPID COMMUNICATION

First observation of the beetle *Sericoderus lateralis* consuming *Cladosporium fulvum* in a greenhouse tomato: potential for biological protection or risk to the crop?

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Abstract

For the first time, the mycophagous beetle *Sericoderus lateralis* (Gyllenhal, 1827) was documented feeding on tomato leaf mold (*Cladosporium fulvum* Cooke, 1878) tissues. The phenomenon was observed during the years 2022 and 2023 in a hydroponic tomato greenhouse situated near the Czech-Polish border within the cadastre of Dolní Lutyně municipality in Czechia. Greenhouse and laboratory observations confirmed that adult and larvae feeding activity led to a reduction in tomato leaf mold lesions. In addition, there was a positive correlation between tomato leaf mold disease progression and increased populations of *S. lateralis* in the tomato crop. Petri dish observations confirmed egg laying occurred on a diet of tomato leaf mold. Further research is warranted to discern whether *S. lateralis* is a potential biological control agent for tomato leaf mold or if it acts to facilitate the spread of the disease by acting as a spore vector.

Keywords: biological control, mycophagy, spore vector, tomato leaf mold

Introduction

Tomato leaf mold (*Cladosporium fulvum*) is a biotrophic fungus that is often found on tomato (*Solanum lycopersicum* L., 1753) plants in protected cropping environments. Under certain conditions, this pathogen can cause significant economic damage (Smith *et al.* 1969; Thomma *et al.* 2005; Aghayev 2022; Sudermann *et al.* 2022). Management of this pathogen involves several synthetic fungicides (Veloukas *et al.* 2007; Hu *et al.* 2023). However, occurrences of resistance are already known (Watanabe *et al.* 2017). Biological methods based on mycoparasitic fungi (e.g., *Trichoderma harzianum*, *Dicyma pulvinata*) are also available although most are preventative in action (Elad 2000; Iida *et al.* 2018).

The family Corylophidae (hooded beetles), classified in the superfamily Cucujoidea, is distributed worldwide and in the West Palaearctic Region. It consists of 45 species in 11 genera (Bowestead 1999). Corylophidae beetles are known to be mycophagous, with both larvae and adults feeding on fungal spores and hyphae of molds and other microfungi. Thus, they are common on and under bark and leaf material and in various accumulations of rotting vegetation, such as leaf litter, hay stacks, cut grass piles, root masses, and dead twigs and branches. Ascomycota and Deuteromycota spore feeding is predominant in the family (Ślipiński *et al.* 2010). The species possess morphological adaptations that enhance their ability to exploit this food source (Lawrence 1989). *Sericoderus lateralis* (Fig. 1L-M) is a parthenogenetic species with a cosmopolitan distribution (Bowestead 1999). It is associated with *Penicillium* occurring in vegetable detritus, and it has also been reared in the laboratory on spores of *Mucor mucedo* (Zygomycetes: Mucorales) and conidia of *Penicillium glaucum* (Ascomycetes: Eurotiales) (Trikhleb and Simutnik 2008). The specimens are usually found in various decaying plant remains, in rotten fungi or under bark partially removed from trees. They can be collected with the use of window traps (Nikitsky and Mamontov 2016). The morphology of adults, pupae, and larvae of *Sericoderus lateralis* was described in detail by Polilov and Beutel (2010) and supplemented by descriptions of thoracic musculature (Polilov 2011) and detailed head morphology (Yavorskaya and Polilov 2016).

Notably, despite these well-documented bionomic and morphological characteristics, there have been no documented observations of Corylophidae beetles feeding on fungal crop pathogens of agricultural importance to date. During standard pest monitoring, the goal of which is to discover new potential or invasive insect pests, the presence of *S. lateralis* was detected. The first observation occurred by chance in 2022. The behavior of beetles and their connection to *C. fulvum* was observed in the years 2022 and 2023.

Materials and Methods

A crucial part of integrated pest management (IPM) in tomato greenhouse crops is regular pest monitoring. At this particular greenhouse (Farma Bezdínek) this crop scouting was carried out on a weekly basis by means of visual inspection of 10% of a crop. If there was a suspicious object the material was checked by using a binocular magnifier. Observations and data collection were conducted in a hydroponic tomato greenhouse with an area of 111 000 m^2, located in the Moravian-Silesian region (Czechia) close to the border with Poland, in the cadastre of Dolní Lutyně municipality.

Under laboratory conditions, the behavior of beetles in 10 Petri dishes was observed during 7 days at a standard room temperature of 20°C and 10 hours light. Samples of living *C. fulvum* and *S. lateralis* for laboratory observations were taken from the greenhouse. Moist filter paper was placed in a Petri dish, on which a leaf with tomato leaf mold was placed. Five adults of *S. lateralis* were then introduced to the same Petri dish (Fig. 1I).

The specimens of *S. lateralis* were identified using the key to western Palaearctic Corylophidae by Bowestead (1999). Photographs of adults (Fig. 1L–M) were taken with a Canon EOS 800D digital camera with a Canon MP-E 65 mm objective lens. Images at different focal planes were combined using Helicon Focus 8 software. The figures were edited with Corel Photopaint 12. Literature data on *S. lateralis* were searched on various databases (Google Scholar, Zoological Records, and others).

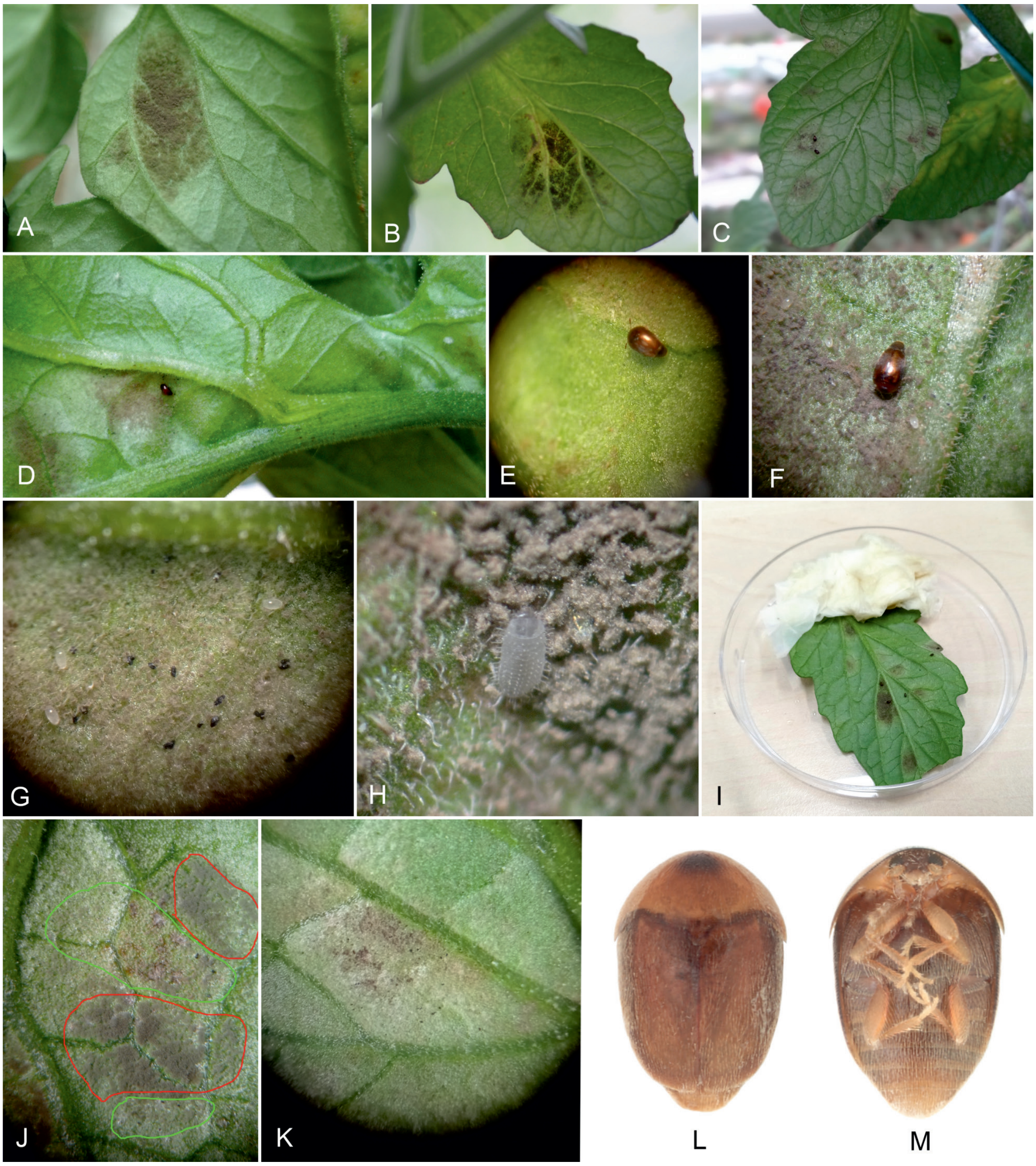
Results

In 2022 and 2023 during the summer and autumn months there was a substantial presence of tomato leaf mold (*C. fulvum*) in the greenhouse (Fig. 1A–B). Increased humidity inside the greenhouse contributed to the development of the disease. Observations of affected leaf surfaces showed the presence of the beetle *S. lateralis*. Individuals of this species were mobile on leaves infested with tomato leaf mold and were often observed in densely diseased areas that consisted of conidiophores (Fig. 1C–E). Later it was observed that the adults actively fed in these areas of *C. fulvum* (Fig. 1F). Most likely, the beetles in the greenhouse had been dispersed through decomposing organic matter on the ground. This organic matter consisted of the remnants of cultivated plants, which had been left beneath the gutter systems. With time, this organic matter becomes colonized by a variety of fungi, including *Botrytis cinerea*, which serve as sustenance (Miller *et al.* 2015).

Using a binocular magnifier, it was possible to observe the development of *S. lateralis*, which included egg laying, directly in disease hotspots (Fig. 1G). Larvae were seen actively feeding on fungal tissue (Fig. 1H). Subsequent closer observation confirmed that the active feeding of adults and larvae led to a reduction of tomato leaf mold on the surface of the leaf.

By October 6, 2022, the tomato leaf mold had already progressed across the entire crop, and a quantitative assessment of occurrence was carried out. In parallel, as *C. fulvum* increased, the population density of *S. lateralis* also increased. In the center of the greenhouse near the central path, it was found that there was an average of 5.5 tomato leaf mold lesions per compound leaf with an incidence of 0.2 adults per lesion. At the end of the crop rows near the glass wall, there was an average of 6.7 tomato leaf mold lesions per compound leaf with an average incidence of 0.5 adults per lesion. Despite a reduction in the size of individual lesions, the impact of *S. lateralis* populations was insufficient to prevent or even slow the disease's spread in the greenhouse. Similar observations were also made in 2023.

It was observed under laboratory conditions that adults laid their eggs directly in diseased areas. On average, out of 10 samples, 4 eggs were deposited in fungal lesions with a diameter of 3 cm. After 4 days, the first larvae appeared in the vicinity of the lesion. Observations of Petri dishes allowed the confirmation



Figs. 1. A–B – tomato leaf mold lesion caused by *Cladosporium fulvum* on the underside of a tomato leaf, C–F – adults of *Sericoderus lateralis* on tomato leaf mold, G – eggs and black excrement of *S. lateralis*, H – larva of *S. lateralis*, I – design of Petri dish observations, J – tomato leaf mold lesion partly consumed (green areas) and not consumed (red areas), K – a hotspot of tomato leaf mold almost entirely consumed by *S. lateralis*, L–M – adult of *S. lateralis* in dorsal and ventral views (body length 1.1 mm)

of active mycophagy in adults and larvae on the tissue of *C. fulvum*. In the closed environment of a Petri dish, five adults were able to consume an entire 5 cm^2 lesion in 48 hours (Fig. 1J–K).

Discussion

Several species of arthropods are known as biological control agents of fungal pathogens (Gracia-Garza *et al.* 1997; English-Loeb *et al.* 1999; Pijnakker *et al.* 2022). Conversely, some mycophages can aid the spread of fungal diseases by facilitating spore distribution around the cropping environment (Hubert *et al.* 2003; Wingfield *et al.* 2017). The observed feeding action of *S. lateralis* on the surface tissues of *C. fulvum* hint at the potential of this species as a biological control agent. In some cases, it has been confirmed that mites can consume fungal mycelia to a significant extent, providing successful control of such diseases in the field (Norton *et al.* 2000; Melidossian *et al.* 2005; Pijnakker *et al.*

2022). In the case of the order Coleoptera, no such reports and experiments have yet been conducted. Our observations did not confirm that a natural population of *S. lateralis* led to a fundamental reduction of tomato leaf mold (*C. fulvum*) on a greenhouse scale, rather, that localized lesions could be controlled in isolation. Further work is required to elucidate whether an inundative application or, a timely preventive application at the beginning of the risk period of *C. fulvum*, could provide sufficient levels of control on a greenhouse scale.

As mentioned previously, the presence of *S. lateralis* in the greenhouse may represent a real threat for cultivated crops. It cannot be ruled out that *S. lateralis*, facilitates the spread of *C. fulvum* in the greenhouse. Indeed, spores can pass through the beetle's digestive tract intact. In this way the species can function as a spore vector, excreting viable spores in feces. This phenomenon has been confirmed in several species of snails (Hoffman and Rao 2013). Interestingly, a similar behavior was confirmed in the fly *Phorbia phrenione*, which lives exclusively on the fungus *Epichloë typhina* (Bultman *et al.* 1998). Spores can possibly be transmitted when attached to the hairs adorning *S. lateralis* adult bodies. In the case of beetles, the transmission of fungal pathogens has already been observed (Harrington *et al.* 2008; Jiang *et al.* 2022). That *S. lateralis* transmits *C. fulvum* spores by some mechanism is also suggested by the observation of a positive correlation between the spread of the tomato leaf mold and *S. lateralis* population densities.

Humid deciduous forests and their soil detritus are one of the natural habitats of *S. lateralis* (Vodka and Cizek 2013; Blažej *et al.* 2022). It is an environment where decaying biomass with the occurrence of various fungal species is common. In the greenhouse, a layer of decaying leaves is located directly under the growing gutters. It is thus certainly a suitable environment for the species. Various species of saprophytic fungi occur in this substrate of plant debris, providing an adequate food source for *S. lateralis* even in the absence of *C. fulvum*.

The current observations of the presence and behavior of *S. lateralis* in a hydroponic tomato greenhouse confirm its position in the group of mycophagous insects and its connection with the fungal species *C. fulvum*. Our observations are the first of this species actively feeding and subsequently completing its lifecycle on the fungus *C. fulvum* which in turn is a serious agricultural disease. Fundamental research into this interaction is still required. Future work should attempt to elucidate whether the importance of this species is positive or negative from the point of view of biological plant protection, and if a viable biological control agent exists in this species.

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