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First detection of *Megaselia scalaris* (Loew) (Diptera: Phoridae) as a facultative endoparasitoid of *Nezara viridula* (L.) (Hemiptera: Pentatomidae)

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Abstract

Background: The phorid fly *Megaselia scalaris* (Loew) (Diptera: Phoridae) is an omnivorous species, capable of exploring a large variety of environments and ecological niches. It is known as an important detritivore species with maggots feeding on a variety of food of both animal and plant origin.

Results: The present study reports *M. scalaris* as an endoparasitoid attacking colonies of the southern green stink bug *Nezara viridula* (L.) for the first time. This case of parasitism was observed inside rearing cages of *N. viridula* at the Plant Protection Research Institute, Dokki, Egypt in August 2020. We firstly identified adult individuals of *M. scalaris* which were found moving erratically within the cages using relevant identification keys. To verify that *N. viridula* individuals are parasitized by the same parasitoid and they are not infected with other parasitoids, some of the parasitized bugs were transferred to a separate cage at the same laboratory conditions and the developmental stages of the dipteran parasitoid were observed until the adult emergence.

Conclusion: The present investigation revealed that *M. scalaris* could be included to the recorded parasitoid species of *N. viridula*, and further studies should be carried out to assess the efficacy of this fly as a biocontrol agent.

Keywords: Scuttle fly, *Megaselia scalaris*, Southern green stink bug, *Nezara viridula*, Biocontrol agent, Egypt

Background

Parasitoid is an organism that attacks any developmental stage of its host, characterized by its larvae which grow on or inside the host and always kill it as part of its life cycle (Godfray and Shimada 1999, Machkour-M'Rabet et al. 2015).

M. scalaris (Loew, 1866) is a cosmopolitan small synanthropic fly (1–6 mm) in the family Phoridae of the order Diptera. Members of this family are commonly known as "scuttle flies" because adults erratically move in rapid bursts with short pauses (Costa et al. 2007). They are also known as "humpbacked flies" due to their humpbacked appearance, and "coffin flies" because adult females are known to dig down two meters deep in order to reach buried corpses and penetrate closed containers such as coffins to lay their eggs (Varney and Noor 2010).

M. scalaris is an omnivorous species, capable of exploring a large variety of environments and ecological niches. It is known as an important detritivore species with larvae (maggots) feeding on a variety of food of both animal and plant origin, and acting as saprophagous, feeding on nourishment from decaying organic matter, sarcophagous, consuming flesh and necrophagous, feeding on corpses or carrion. However, protein food sources are preferred by the females for maturation of their eggs. These feeding habits make this species a

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facultative predator, parasite, and parasitoid on/in other invertebrates under natural and laboratory conditions (Sukontason et al. 2003, Costa et al. 2007, Disney 2008).

M. scalaris was reported as a parasitoid of some insect species of agronomic and medical importance, including members of the following orders: Hemiptera (Costa et al. 2007), Orthoptera (De Gregorio and Leonide 1980, Quesada-Béjar et al. 2017), Mantodea (Koch et al. 2013), Lepidoptera (Ulloa and Hernandez 1981, Souza et al. 2020), Diptera (Batista-Da-Silva 2012, Marchiori 2018), and Coleoptera (Harrison and Gardner 1991, Arredondo-Bernal and Trujillo-Arriaga 1994).

Some cases of animal myiasis caused by *M. scalaris* in a rattlesnake were reported in Brazil (Silva et al. 1999), and infestation of frog eggs was reported in Panama (Brown and Horan 2012). Furthermore, facultative and accidental myiases by *M. scalaris* in nasopharyngeal, intestinal, and leg wound were reported in hospitalized patients in Kuwait and Egypt were recorded (Hira et al. 2004, Mazayad and Rifaat 2005).

The egg of *M. scalaris* is small and boat-shaped. It is characterized by its gunwale-like palisade of flat platelets that surround the respiratory plastron with its scattered tubercles. Eggshells are more resistant towards unfavorable factors such as bacteria attack and dryness (Wolf and Liu 1996, Disney 2008). The larva (maggot) of *M. scalaris* is almost creamy white and undergoes two molts leading to three larval instars. The first and second larval instars measure 0.75–2 mm in length, cylindrical, narrowed toward the head, with two cephalic lobes are found on cephalic region and six sensory papillae positioned tangential to the antenna (Boonchu et al. 2004). The third larval instar is similar to the first and second ones. However, it is usually more than 2 mm in length with spiracular hairs appearing centrally at the constriction of the slender spiracular plates (Sukontason et al. 2002), and this instar can be subdivided into two stages, feeding stage and post-feeding stage (Greenberg, 1991). Pupa of *M. scalaris* is dorsoventrally flattened with an invaginated cephalic segment, with a pair of long and slender pupal respiratory horns at the end of the fifth dorsal segment. Several spiral papillae are arranged on the respiratory surface of these horns. The papillae are oval and domed-shaped with a single longitudinal straight aperture on them. There is an invaginated cephalic segment with a pair of antennae at the ventral part. A pair of round anterior spiracles is found dorsolateral on the prothorax (Sukontason et al. 2005). The adult *M. scalaris* is small (1–6 mm in length) with a humpbacked appearance, it can be distinguished by the following characters: Frons brownish-yellow, with dense fine microsetae; scutum brown dorsally; scutellum pale brownish-yellow, with two pair of bristles; costa extends more than half wing length, vein R_{2+3} present; legs long, yellowish in color; mid-tibia without paired bristles; hind tibia without differentiated antero-dorsal hairs, with a dorsal hair palisade; hind femur with a brown tip; abdominal tergites dark brown with yellowish markings; palps straw yellow; tip of anal tube with feathered bristles (Alam et al. 2016, Zhang et al. 2017).

M. scalaris was recorded from Egypt (Steyskal and El-Bialy 1967). Abdel-Gawad (2018) and Ismail (2018) reared it in Ain Shams University, Cairo, Egypt, for morphological studies. However, no extensive taxonomic or faunistic studies have been carried out to indicate the exact distribution of this species or its relative phorid species in Egypt.

The southern green stink bug, *Nezara viridula* (Linnaeus, 1758) (order Hemiptera: family Pentatomidae), is a cosmopolitan bug species distributed throughout the tropical and sub-tropical regions of Africa, America, Asia, and Europe. This bug is considered as one of the most important damaging pests all over the world. It is a highly polyphagous insect, attacking a wide range of grain, fruit, and vegetable crops including beans, cabbage, citrus, cotton, nuts, rice, sugarcane, and wheat, with a preference for leguminous plants. Adults and nymphs of *N. viridula* feed on plant fluids by piercing plant tissues with their piercing-sucking mouthparts. Adults cause maximum damage attacking all parts of plant including stem, petioles, foliage, flowers, fruits, and seeds. Feeding on flower buds causes premature abscission, and damage to seed pods (Hoffman 1935, Corpuz 1969, Hussain and Saharia 1994, Sudan 2008, Tara and Sharma 2010).

In Egypt, heavy infestations and damaging outbreaks of *N. viridula* were reported on citrus in some Egyptian governorates including Menofieh, Gharbieh, and Sharkieh in October 1973, the infestation was observed also on some adjacent crops as maize, vegetables (especially cabbage) and sesame (Attiah et al. 1974, Ali et al. 1978). According to El Maghrabi (1998) and our observations, this bug is distributed in all Egyptian ecological zones: coastal strip, lower Nile Valley and Delta, Fayoum, Western Desert, Eastern Desert, upper Nile Valley, Sinai, and Gebel Elba. It was detected throughout the year attacking fruits and major field crops including rice (*Oryza sativa* L.), sugar cane (*Saccharum officinarum* L.), wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), cotton (*Gossypium barbadense* L.), alfalfa (*Medicago sativa* L.), clover (*Trifolium alexandrinum* L.), sesame (*Sesamum indicum*), okra (*Abelmoschus esculentus* (L.)), potato (*Solanum tuberosum* L.), tomato (*Solanum lycopersicum* L.), faba bean (*Vicia faba* L.), mango (*Mangifera indica* L.), and citrus (*Citrus* spp.).

Methods

This study is based on hundreds of individuals of all developmental stages of *M. scalaris* found parasitizing the

southern green stink bug *N. viridula* which was reared at the Department of Piercing and Sucking Insects, Plant Protection Research Institute, Agricultural Research Centre, Dokki, Egypt.

In the present case of parasitism, the adults of *M. scalaris* were first observed in August, 2020 and the study continued for four consecutive months until the end of November 2020. The reared bugs were originally collected from a field cultivated with faba bean at the farm of "Faculty of Agriculture, Cairo University, Giza, Egypt" in October 2018. Female and male adults of *M. scalaris* (Fig. 1a) were found moving erratically within the cages, while eggs, larvae and pupae (Fig. 1b, c) were observed on or inside the bodies of some dead or parasitized bug individuals. Adult individuals of *M. scalaris* were firstly identified using Disney (1994, 2008). To verify that they are parasitized by the same parasitoid and not infected with other parasitoids, some of the parasitized bugs were transferred to a separate cage at the same laboratory conditions and the developmental stages of the dipteran parasitoid were observed until the adult emergence. After about 1 week, tens of male and female adult individuals of *M. scalaris* emerged in the cage. Some of living or newly dead parasitized bugs were dissected to check the larvae and pupae of the parasitoid within it (Figs. 2, 3, and 4). The parasitoid larvae, pupae, adults, and the parasitized bugs were photographed. Some identified adults of *M. scalaris* were deposited in two Egyptian collections: the collection of the Entomology Department, Faculty of Science, Cairo University (Efflatoun Bey's collection) and the Collection of the Ministry of Agriculture, Plant Protection Research Institute, Dokki, Giza.

Results

The parasitoid: *Megaselia* (*Megaselia*) *scalaris* (Loew, 1866)

Synonyms:

Aphiochaeta banski Brues, *Aphiochaeta circumsetosa* Meijere, *Aphiochaeta ferruginea* Brunetti, *Aphiochaeta fissa* Becker, *Aphiochaeta repicta* Schmitz, *Aphiochaeta xanthina* Speiser, *Lioyella plusiivorax* Enderlein, *Megaselia ferruginea* (Brunetti), and *Megaselia forticapilla* Beyer.

World distribution:

Cosmopolitan.

Local distribution:

According to our observations and available museum specimens preserved in Efflatoun Bey's collection in Cairo University and the Collection of the Ministry of Agriculture in Plant Protection Research Institute, this species was recorded from: Coastal Strip (Alexandria, Mariout); Lower Nile Valley and Delta (Abbassiya, Abu-Ghalib, Gezeira, Giza, Pyramids); Fayoum (Kom Osheem, Sennouris); Western Desert (Wadi El-Natroun). The dates of collection extended from April to December.

The host: *Nezara viridula* (Linnaeus, 1758)

Synonyms:

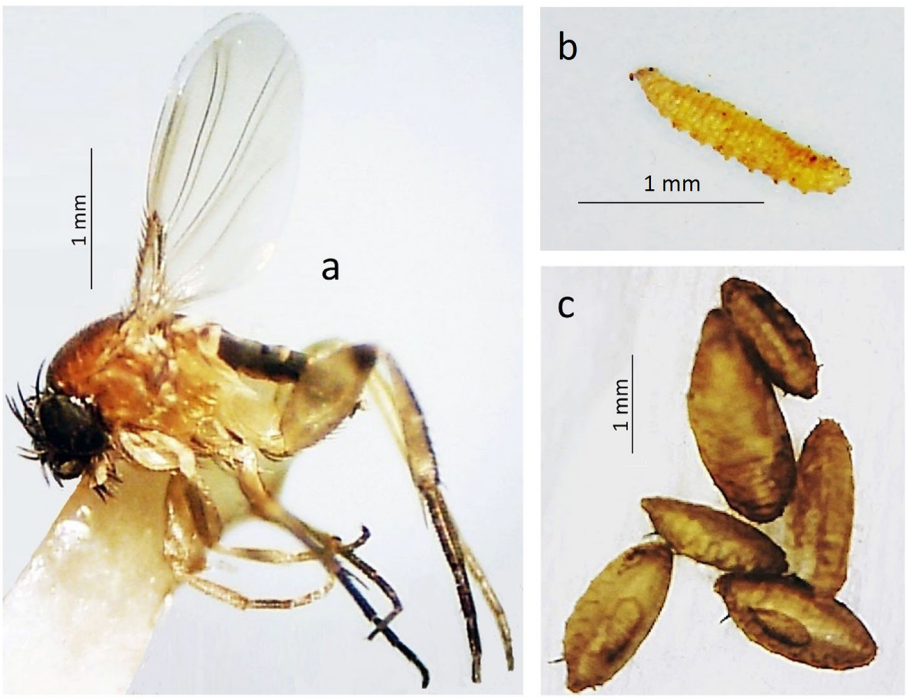

Fig. 1 *Megaselia scalaris* (Loew). **a** Adult female, lateral view. **b** First larval instar. **c** Pupae

Fig. 2 a–f emergence of third larval instar of *Megaselia scalaris* from head of *Nezara viridula* (L.) for pupation

Cimex smaragdulus Fabricius, *Cimex viridulus* Linnaeus and *Nezara smaragdulus* (Fabricius).

World distribution:

Cosmopolitan.

Local distribution:

According to our observations, El Maghrabi (1998) and museum specimens preserved in Efflatoun Bey's collection in Cairo University and the Collection of the Ministry of Agriculture in Plant Protection Research Institute, this species was recorded throughout the year from different localities representing all Egyptian ecological zones, as follows: coastal strip (Alexandria, Balteem and Burg El-Arab); lower Nile Valley and Delta (Abu-Ghalib, Abu-Katata, Abu-Rawash, Aga, Ashmoun, Birqash, El-Bustan (Beheira), El-Hager, El-Gabal El-Asfar, El-Marg, Gharbieh, Giza, Helwan, Kirdassa, Maadi, Sharkieh, Wardan, Zifta); Eastern Desert (Ismailia, Suez, and Wadi Degla); Western Desert (Bahariya Oasis, Dakhla Oasis, Kharga Oasis, and Wadi El-Natroun); Fayoum (Fayoum City, Kom Osheem, Sennouris, and Tamiya); upper Nile Valley (Assiout, Beni Hussein, Beni Sweif, Edfo, Manfalout, Shandaweil, and Sohag); Sinai (El-Arish); Gebel Elba (Wadi Shallalah).

Observations

Firstly, many dead individuals of *N. viridula* were noticed by the third author within the rearing cages of the

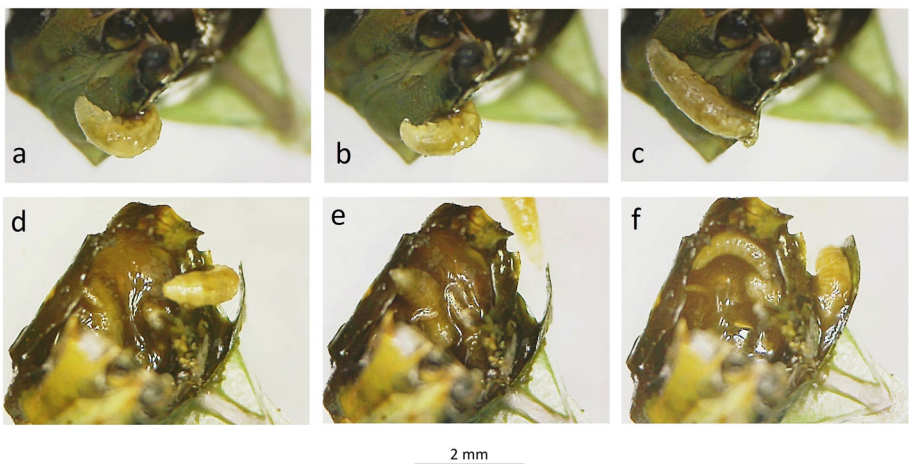

Fig. 3 a–f emergence of third larval instar of *Megaselia scalaris* from thorax of *Nezara viridula* (L.) for pupation

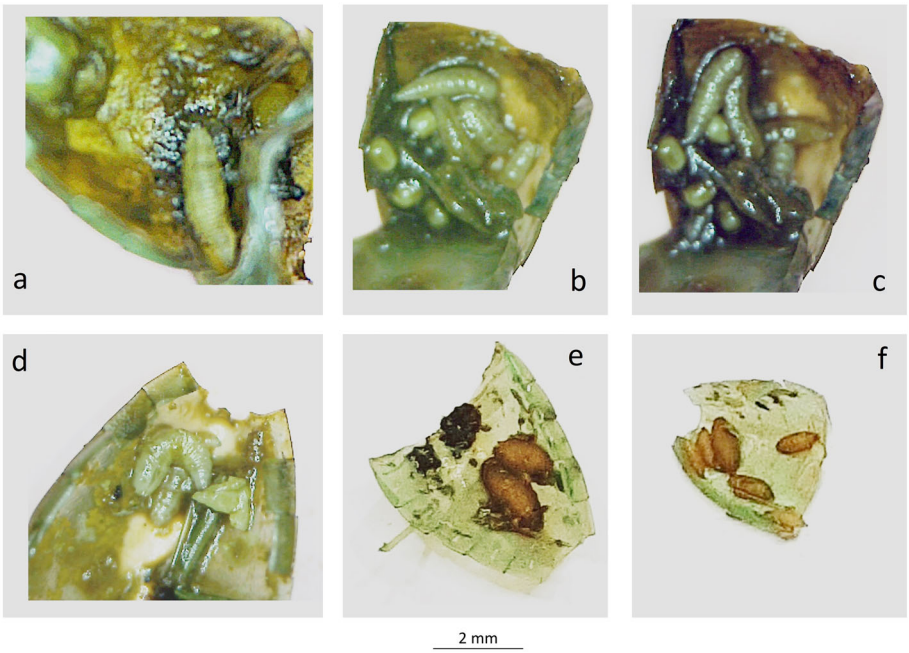

Fig. 4 **a**–**d** Third larval instar of *Megaselia scalaris* inside a dissected abdomen of *Nezara viridula* (L.). **e**, **f** Pupae of *Megaselia scalaris* inside a dissected abdomen of *Nezara viridula* (L.)

bug. Since then, we have tried to investigate the cause of this abnormal death. In this regard, we carefully observed and checked the colony. We noticed that all developmental stages of the phorid fly *M. scalaris* were found within the rearing cages of *N. viridula* or on/in the bodies of nymphs and adults of the bug. Consequently, some of the parasitized bugs were transferred to a separate cage at the same laboratory conditions and the developmental stages of the dipteran parasitoid were observed until the adult emergence.

Adults of the fly (Fig. 1a) were found moving erratically within the cages. Eggs were found adhering to head, thorax, and abdomen of the host bug. First instar larvae (Fig. 1b) hatched after 3–5 days at room temperature, about 30 °C, and then they penetrated the bug integument entering its body and feeding on the internal body fluids and tissues for about 1–2 weeks. It seemed that larvae penetrated from the site where they emerged as no specific entrance points were detected. The parasitized bugs usually died after the infection, and mature larvae (third instar) leave their host after completion of the larval stage and emerge outside the host body (Figs. 2 and 3). Mature larvae began to pupate immediately after emergence in soil at the floor of cage. Some larvae may not be able to leave the host bug, so they pupate inside it (Fig. 4e, f). Pupation required about 1 week before adult emergence.

The dissection of living or newly dead parasitized bugs confirmed that larvae of *M. scalaris* developed inside all body regions of the host bug, head (Fig. 2), thorax (Fig. 3), and abdomen (Fig. 4a–d), consuming the internal organs. A large number of larvae was observed in abdomens of dissected bugs, usually more than 40 larvae per abdomen (Fig. 4a–d), while in head and thorax the number was less than 10 larvae in each (Figs. 2 and 3). The internal organs of the parasitized bugs were found destroyed, as no viscera could be found. Other bugs were found semi-destroyed, as only a portion of the digestive system was destroyed. To some extent, thoracic muscle tissues of parasitized bugs showed some destruction. This may interpret why parasitized bugs move with difficulties before death.

Discussion

The larvae of *M. scalaris* have been described as detritivore, parasite, and parasitoid, consuming a wide spectrum of organic materials of both animal and plant origin (Disney, 2008, Koch et al. 2013).

M. scalaris is detected in the present study as a facultative endoparasitoid of the southern green stink bug *N. viridula* for the first time. However, this finding is not surprising as it was reported as a parasitoid of some insect species of agronomic and medical importance, such as the Chagas disease vector *Triatoma brasiliensis* Neiva [Reduviidae, Hemiptera] (Costa et al. 2007), the grasshoppers *Zonocerus variegatus* (L.), and *Sphenarium purpurascens* Charpentier [Pyrgomorphidae, Orthoptera] (De Gregorio and Leonide 1980, Quesada-Béjar et al.

2017), the mantid *Parastagmatoptera tessellata* Saussure and Zehntner [Mantidae, Mantodea] (Koch et al. 2013), the pre-pupae of the variegated cutworm or pearly underwing moth *Peridroma saucia* (Hübner) [Noctuidae, Lepidoptera] (Ulloa and Hernandez 1981), the caterpillars of the hawk moth *Isognathus caricae* (Linnaeus) [Sphingidae, Lepidoptera] (Souza et al. 2020), the blowflies *Chrysomya*, and *Cochliomyia* spp. [Calliphoridae, Diptera] (Batista-Da-Silva 2012), the pupae of the black scavenger fly *Palaeosepsis* sp. [Sepsidae, Diptera] (Marchiori 2018), the adults of the pecan weevil *Curculio caryae* (Horn) [Curculionidae, Coleoptera] (Harrison and Gardner 1991) and the rose chafer *Macrodactylus murinus* Bates [Scarabaeidae, Coleoptera] (Arredondo-Bernal and Trujillo-Arriaga 1994).

M. scalaris could have a potentiality to control *N. viridula* side by side with some tachinid flies which have been detected as endoparasitoids of this bug, such as *Ectophasia crassipennis* (Fabricius) and *Trichopoda pennipes* (Fabricius) (Cerretti and Tschorsnig 2010, El-Hawagry et al. 2020).

Conclusion

In the present study, the scuttle fly *Megaselia scalaris* (Loew) (Diptera: Phoridae) was detected as a facultative endoparasitoid of the southern green stink bug *Nezara viridula* (L.) (Hemiptera: Pentatomidae) for the first time in laboratory colonies of this bug in Egypt. The present investigation revealed that *M. scalaris* could be included to the recorded parasitoid species of *N. viridula*, and further studies should be carried out to assess the efficacy of this fly as a biocontrol agent.

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Authors' contributions
ME identified the host fly and drafted the manuscript. AE participated in identifying the host fly. MN reared and observed the host bug, dissected, and photographed some parasitized bugs. All authors participated in the study design and coordination and interpreted the data. All authors have read and approved the manuscript.

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Competing interests
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