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Mealybugs (Hemiptera, Pseudococcidae) and their parasitoids on vegetables in protected agriculture in México

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Abstract

In the current century, there has been an increase in vegetable production in protected agriculture, as well as an increasing incidence of some insect pests. For example, some hemipterans such as mealybugs are sometimes a problem with greenhouse vegetables, but farmers do not have the same problem with vegetables grown in open fields. The objective of this work was to identify species of mealybugs and their natural enemies on vegetables in protected agriculture in México. Sampling was carried out in greenhouses and net houses, mainly in pepper and tomato, from 11 regions of the country. Mealybugs adult females were collected for processing and mounting, and some mealybugs immature and adults were kept in net devices to record the emergence of their parasitoids. Four species of mealybugs were identified, *Phenacoccus solenopsis* Tinsley, *Phenacoccus solani* Ferris, and *Phenacoccus madeirensis* Green were collected more frequently; *Ferrisia virgata* Cockerell (Hemiptera: Pseudococcidae) was recovered only once. Ten species of parasitoids were identified: *Acerophagus angelicus* Howard, *Aenasius arizonensis* Girault, *Dicarnosis ripariensis* Kerrich, *Cheiloneurus* sp. Westwood, *Ectromaptosis americana* Howard, *Anagyrus paralia* Noyes and Menezes, *Holcencyrtus osborni* Timberlake, *Anagyrus tristis* Noyes and Hayat (Hymenoptera: Encyrtidae), *Chartocerus axillaris* De Santis (Hymenoptera: Signiphoridae) and *Allotropa* sp. Förster (Hymenoptera: Platygastridae). Three of them were first recorded in México, and six had a new host record.

Key Words

biological control, Encyrtidae, natural enemies, *Phenacoccus*

Introduction

Mealybugs (Hemiptera: Pseudococcidae) are insects that suck sap from plants and cause damage such as discoloration of foliage and necrosis of leaf edges; in addition, they can be vectors of some plant viruses (Selvarajan et al. 2016; Subramanian et al. 2021). They also excrete honeydew, which causes the growth of sooty mould which decreases plant photosynthetic rates; the presence of mealybugs, honeydew or sooty mould in fruits and foliage causes rejection of products in national and international trade (Mani and Shivaraju 2016; Palma-Jiménez et al. 2019; Subramanian et al. 2021). About 25% of mealybugs are polyphagous, and some species of the genus *Planococcus* Ferris, *Phenacoccus* Cockerell, *Pseudococcus* Westwood and others are vegetable pests in open field and greenhouses (Moreno-Salmerón 2011; Knapp et al. 2020; Subramanian et al. 2021).

Different mealybugs species such as *Planococcus citri* Risso, *Phenacoccus madeirensis* Green, *Phenacoccus solani* (Ferris), and *Pseudococcus comstocki* Kuwana (Hemiptera: Pseudococcidae) have a cosmopolitan distribution and a wide range of host plants (William and Granara de Willink 1992; Ben-Dov 1994). However, when it comes to mealybugs associated with vegetables, *P. madeirensis*, *P. solani*, and *P. solenopsis* are species with a wider distribution in Asia, Europe, and Africa, and to a lesser extent in America (García Morales et al. 2016).

In the United States of America there are about 1,100 mealybug species, and 37 are considered economically important pests (Howell and Williams 1976; García Morales et al. 2016). In California, USA, there are several species of *Planococcus*, *Pseudococcus*, *Chorizococcus* McKenzie, *Ferrisia* Fullaway, *Antonina* Signoret, *Phenacoccus*, *Trionymus* Berg, *Heterococcus* Ferris (Hemiptera: Pseudococcidae) and *Rhizoecus* Kunckel d'Herculais (Hemiptera: Rhizoecidae), which have been reported mainly attacking fruit and ornamental trees in greenhouses or nurseries (McKenzie 1967; García Morales et al. 2016). In Mexico, about 636 species of mealybugs are considered potential pests, most of them are hosted by fruit and ornamental trees (Miller et al. 2002; García Morales et al. 2016), but recently *P. madeirensis* was reported on greenhouse peppers in Texcoco, Estado de Mexico and *P. solenopsis* on cotton in Mexicali, Baja California (Lomeli-Flores et al. 2021). On the other hand, in the Central and South American countries, 131 species of Pseudococcidae are reported from 73 host plant families (Williams and Granara de Willink 1992).

Because of the biology and behavior of mealybugs, their management requires several control tactics in the IPM strategy (Jahn 1992; Gutierrez et al. 2008; Venkatesan et al. 2016). One of the most effective tactics is introduction and augmentation biological control (Franco et al. 2009; Beltra et al. 2013). For example, one of the most effective natural enemies used to control mealybugs is *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae) (Kairo et al. 2013; Gunawardana and Hemachandra 2020). This coccinellid is excellent in high mealybug densities, but not very effective in low prey densities, so it is very often combined with a parasitoid (Moore 1988; Chong and Oetting 2007; Hernández-Moreno et al. 2012; Kairo et al. 2013). In Nayarit, México, and California, USA, *Anagyrus callidus* Triapitsyn, Andreason and Perring (Hymenoptera: Encyrtidae) and *C. montrouzieri* were used for the control of *Maconellicoccus hirsutus* Green (Hemiptera: Pseudococcidae) with successful results in both countries (García-Valente et al. 2009; Perring et al. 2022; Lomeli-Flores et al. 2024).

Due to the increase of vegetable cultivation in protected agriculture in the world (there are around 405,000 ha), the incidence of some pests such as mealybugs has also increased (Gastelum and Godoy 2016; Reddy and Reddy 2016). In México, protected agriculture has increased 40,000 ha in the last 20 years (Lomeli-Flores et al. 2020; AMPHAC 2022; SADER 2022), and growing vegetables such as tomato and pepper in greenhouse and net houses, has been associated to the incidence of mealybugs on them (Gastelum and Godoy 2016; Haider and Rai 2021). This situation is a disadvantage for greenhouse vegetable growers in México who already practice biological control as an indispensable tool within the Integrated Pest Management (Lomeli-Flores et al. 2020, 2024), because they have only two species of commercial predators, but not parasitoids to control mealybugs (Acevedo-Alcalá et al. 2024a). In Europe, some mealybug parasitoids are used in greenhouse vegetables (Van Lenteren et al. 2020). Nevertheless, these cannot be introduced into North America, and specifically into Mexico, until the international phytosanitary measures are complied, which must be evaluated using risk analysis before any displacement (Mason et al. 2017). This situation temporarily limits availability of parasitoids for control of mealybugs in México. For this reason, it is essential to increase knowledge of the native natural enemies of mealybugs in North America and particularly in México, where there is probably a greater diversity of species because of the biological and ecological diversity in the country. The objective of this work was to identify the species of mealybugs that attack vegetables in protected agriculture in México and their associated parasitoids.

Materials and methods

Collection of field material

Between 2020 and 2024, sampling was carried out in the main horticultural areas of México where vegetables are grown in greenhouses and net houses, according to crop cycles of each region. In all regions selected for sampling, collaboration was established with technicians from different vegetable producing companies. In this way, material was collected from 11 states of the country, including some of the main vegetable-producing places mainly in the West and Northwest (Michoacán, Jalisco, Nayarit and Sinaloa), and in the Central region (San Luis Potosí, Guanajuato, Querétaro, Hidalgo, Puebla and Estado de México). We also recovered a few samples from the Northeast (Tamaulipas). The greatest number of mealybug samples were collected from bell peppers and tomatoes, and to a lesser extent cucumber. One sample of a pepper variety that is less important in protected agriculture was also included, mirasol chili pepper (*Capsicum annuum* L., Mirasol). Adult mealybug females were placed in 1.5 mL Eppendorf tubes with 70% ethanol. In addition, some immature stems and shoots of pepper or tomato plants, infested with mealybugs, were cut and placed in 200 mL plastic containers, and this material was kept in the laboratory (25 ± 2 °C, 75 ± 5% RH and 12:12 h L: D) to await the emergence of associated natural enemies. Each sample was labeled for identification with host plant, date and collection place.

Identification of mealybugs and parasitoids

All samples were transferred to the biological control laboratory of the Colegio de Postgraduados, *Campus* Montecillo, Texcoco, Estado de México. To prepare adult mealybug females for slide-mounting, they were first macerated in an Eppendorf tube (1.5 mL) using 10% KOH at 80 °C for 10 min (AccuBlock, Labnet, Edison, NJ). Subsequently, the Kosztarab (1963) technique was used for pro-

cessing and slide-mounting adult female specimens. The mealybug fixed specimens were identified using the keys of Williams and Granara de Willink (1992) and Kaydan and Gullan (2012). Mealybug species were identified by the first author and then corroborated by H.G-H. The specimens for safekeeping were deposited in the Insect Collection of the Colegio de Postgraduados. For preservation and reference, they were assigned the numbers: PHCa.01 to PHCa.10, PHSL.01 to PHSL.06 and PHCs.01 (where PH = mealybug, Ca = *Capsicum annuum*, SL = *Solanum lycopersicum*, and Cs = *Cucumis sativus*).

The preservation and mounting of parasitoids was carried out following the methodology of Lomeli-Flores et al. (2021). Based on available morphological descriptions for Encyrtidae (Noyes and Hayat 1994; Trjapitzin et al. 2008), male and female specimens were separated. Then a male and female adults were taken, and several structures were dissected and placed on a slide using a drop of glycerin, then covered with a coverslip. This preparation was placed in an Optika B-510PH compound microscope, and photographs of the diagnostic structures were taken (Canon EOS T7 digital camera). To identify at the genus level, we used the dichotomous keys of Noyes and Hayat (1994); Gibson et al. (1997), and Trjapitzin et al. (2008). To identify at the species, we used specific dichotomous keys and the original descriptions when available: Howard (1898), Kerrich (1978), Rosen (1981), Noyes and Hayat (1994), Noyes and Woolley (1994), Noyes and Ren (1995), Noyes (2000), Veenakumari et al. (2013), and Triapitsyn et al. (2014). Parasitoid species were identified by the first author and validated by J.R.L-F., a specialist in this taxonomic group. Specimens of the parasitoids were deposited in the Insect Collection of the Colegio de Postgraduados with the voucher numbers: CAEM-Hy-022 to CAEM-Hy-029.

Results

The incidence of mealybugs is not widespread in protected agriculture in México. This can be indicated because, in several regions, it was necessary to search for material for more than a season or different year to detect mealybugs. From 19 collection sites in 11 different regions of the country four species of mealybugs were identified, but only three were more abundant: *Phenacoccus solenopsis*, *P. solani* and *P. madeirensis*. All three were recovered mainly from pepper and tomato; the fourth species, *Ferrisia virgata*, was only identified in one pepper sample from Jala, Nayarit. In addition, eight species and two genera of parasitoids associated with these mealybugs were identified (Fig. 1, Table 1).

This is the first record in México of *P. solani* on cucumber, *F. virgata* on pepper and *P. solenopsis* on pepper and tomato. The natural enemies were only recovered from five locations out of 19. These locations were Texcoco, Estado de México; Vallejos and Santa Teresa, San Luis Potosí; Chilcuautla, Hidalgo, and Chulavista, Sinaloa (Table 1, Figs 2, 3).

Discussion

The four species of mealybugs identified in this work (*P. solenopsis*, *P. solani*, *P. madeirensis* and *F. virgata*) are polyphagous, and they are reported in the five continents infesting vegetables, fruit trees and ornamentals (Ben-Dov 1994; García Morales et al. 2016). In México there was a record of these mealybugs in some field host plants (Williams and Granara de Willink 1992). For example, *P. solenopsis* was associated with cotton and hibiscus in

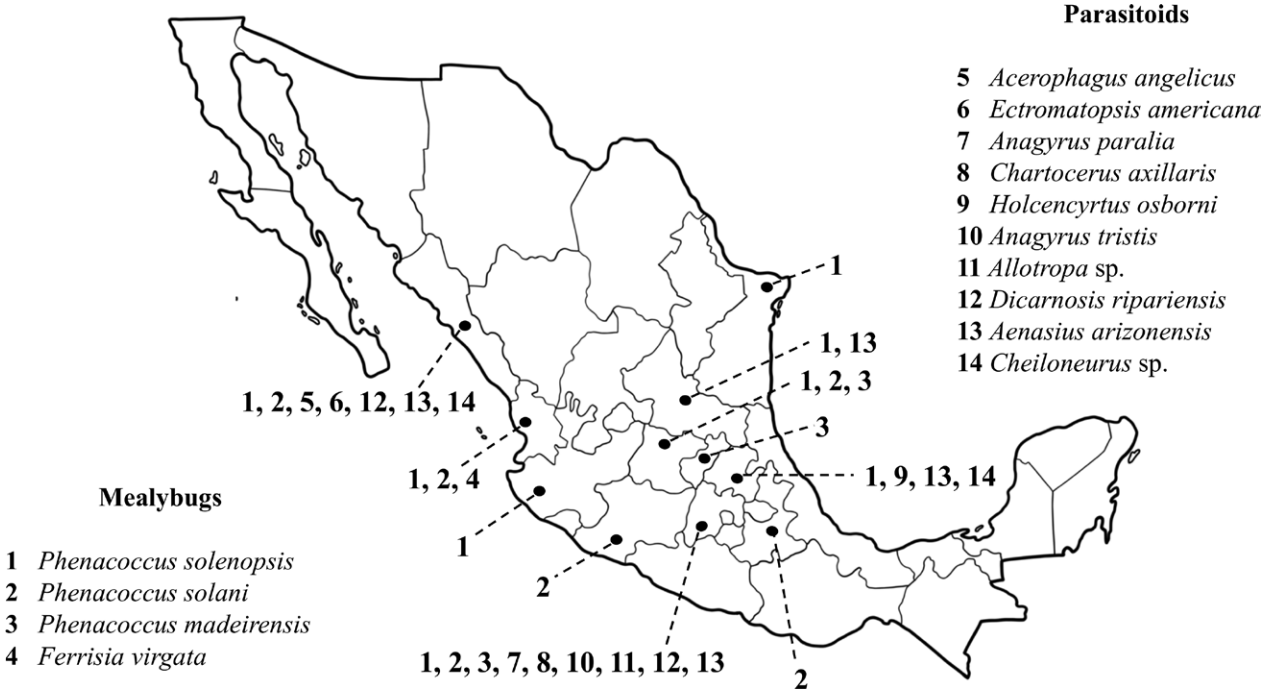

Figure 1. Mealybugs and their parasitoids collected on vegetables in protected agriculture in México.

Table 1. Mealybugs and their associated natural enemies collected on vegetables in protected agriculture in México.

Mealybug species	Collection date	Locality	Host	Natural enemies
Phenacoccus solenopsis	25/05/2023	Etzatlán, Jalisco	Bell pepper	–
	05/04/2024	Costa Rica, Culiacán, Sinaloa		–
	05/04/2024	La Fortuna, Sinaloa		–
	02/12/2020	Culiacán, Sinaloa		–
	08/04/2024	Jala, Nayarit		–
	12/02/2020	Pénjamo, Guanajuato		–
	28/08/2023	Rebalín, San Luis Potosí SLP		–
	28/08/2023	Piedra Colorada, SLP	Mirasol pepper	–
	01/04/2023	La Libertad, Ciudad Victoria, Tamaulipas	Tomato	–
	05/04/2024	Aguaruto, Culiacán, Sinaloa		–
	25/08/2023	Montecillo, Texcoco, Estado de México		*Anagyrus paralia*[2] *Aenasius arizonensis*
	21/07/2023	Vallejos, San Luis Potosí		Cecidomyiidae
	21/06/2023	Santa Teresa, San Luis Potosí		*Aenasius arizonensis*
	13/06/2024	Chilcuautla, Hidalgo		*Cheiloneurus* sp. *Aenasius arizonensis* *Holcencyrtus osborni*[2]
	30/05/2023	Montecillo, Texcoco, Estado de México	Cucumber	–
	04/04/2024	Aquixtla, Puebla	Tomato	–
Phenacoccus solani	19/04/2023	La Piedad, Michoacán	Bell pepper	–
	27/04/2023	Jala, Nayarit		–
	10/02/2021	Pénjamo, Guanajuato		–
	08/03/2023	Chulavista, Culiacán, Sinaloa		*Acerophagus angelicus* [1] *Aenasius arizonensis* [2] *Cheiloneurus* sp. [2] *Ectromatopsis americana* Cecidomyiidae
Phenacoccus madeirensis	12/08/2024	Montecillo, Texcoco, Estado de México	Tomato	–
	15/01/2020	Juventino Rosas, Guanajuato	Mini bell pepper	–
	06/01/2020	Pénjamo, Guanajuato		–
	10/02/2020	Pénjamo, Guanajuato	Bell pepper	–
	03/02/2021	Tlacote el Bajo, Querétaro		–
	25/08/2023	Montecillo, Texcoco, Estado de México		*Dicarnosis riparіensis* *Anagyrus tristis* *Allotropa* sp.[1,2] *Chartocerus axillaris* [1,2]
Ferrisia virgata	08/04/2024	Jala, Nayarit	Bell pepper	–

[1]New registration for México; [2]New host record; -- No recovered.

México (Lomeli-Flores et al. 2021; Galvez-Marroquin et al. 2023). *Ferrisia virgata* was identified from tomato in open field (Williams and Granara de Willink 1992; Arriola-Padilla 2009); *Phenacoccus solani* was only recorded on some ornamental plants in México (Williams and Granara de Willink 1992), while *P. madeirensis* had been reported on vegetables such as tomato and pepper (Williams and Granara de Willink 1992; Lomeli-Flores et al. 2021).

Four species of parasitoids were identified on *P. solani* in Chulavista, Culiacán, Sinaloa: *Acerophagus angelicus* Howard, *Aenasius arizonensis* Girault, *Ectromaptosis americana* Howard, and an unidentified species of the genus *Cheiloneurus* Westwood (Hymenoptera: Encyrtidae). We also found an unidentified species of Cecidomyiidae (Diptera) whose larvae apparently preyed on immatures of this mealybug species. We recovered some *Dicarnosis riparіensis* Kerrich (Hymenoptera: Encyrtidae) adults from Sinaloa; however, based on laboratory observations, the parasitoid did not reproduce on *P. solani*, and therefore cannot be considered its host (unpublished data). The *D. riparіensis* specimens recovered from Sinaloa were adults flying around colonies of mealybugs in some net houses, so it is very likely that this association was accidental because the parasitoid was looking for some other host or foraging honeydew on plants.

Four species of *P. solenopsis* parasitoids were identified from two localities of the central region of Mexico (Estado de México and Hidalgo): *Anagyrus paralia* Noyes and Menezes, *A. arizonensis*, *Holcencyrtus osborni* Timberlake (Hymenoptera: Encyrtidae), and a species of *Cheiloneurus* sp. On the other hand, in *P. madeirensis* four species of parasitoids were identified on bell pepper in Texcoco, Estado de Mexico: *D. riparіensis*, *Anagyrus tristis* Noyes and Hayat, *Chartocerus axillaris* De Santis and an unidentified species of *Allotropa* Förster (Hymenoptera: Platygastridae). The first two species having already been reported as parasitoids of this mealybug in the same locality (Lomeli-Flores et al. 2021; Acevedo-Alcalá et al. 2024b). *Chartocerus axillaris* represented a new record in the country and new host record. In the case of the genus *Allotropa*, species-level identification was not achieved. In the American Continent and México species of *Allotropa* have been recorded, although most have only been identified at the genus level (Pacheco da Silva et al. 2021; GBIF 2025).

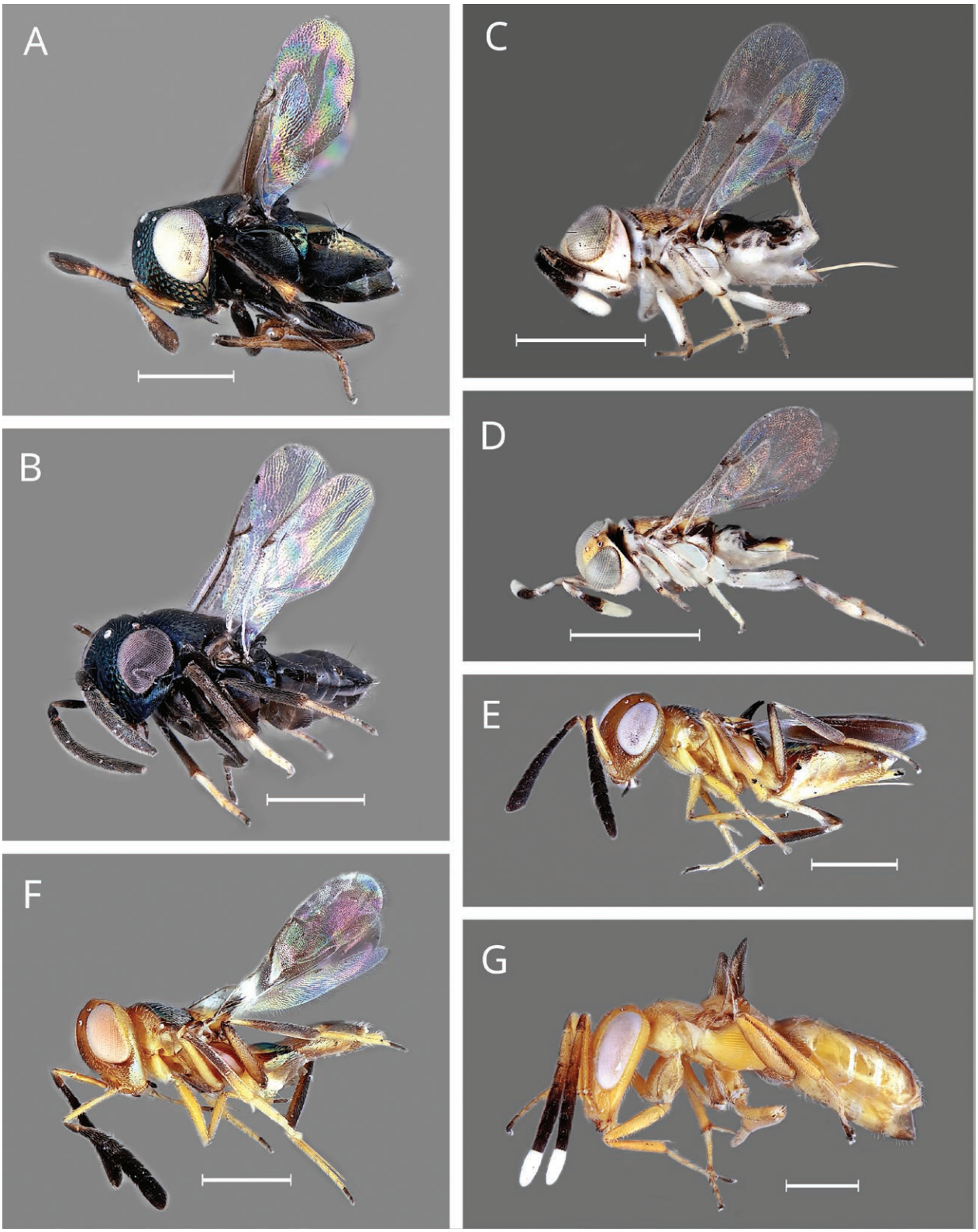

Figure 2. Parasitoids associated with mealybugs in protected agriculture in México. **A.** *Aenasius arizonensis* female; **B.** *A. arizonensis* male; **C.** *Acerophagus angelicus* female; **D.** *A. angelicus* male; **E.** *Cheiloneurus* sp. female; **F.** *Cheiloneurus* sp. male, and **G.** *Ectromaptosis americana* female. Scale bars: 500 μm.

However, *Allotropa gundlupetensis* Veenakumari & Buhl is the only species reported as a parasitoid of *Phenacoccus madeirensis* (Veenakumari et al. 2013).

The parasitoids *A. angelicus* and *E. americana* had been recorded in the United States on *P. solani* (Poinar 1964; Noyes and Hayat 1994), and now two additional natural enemies were recorded which parasitize this mealybug species (Table 1). Something similar happened with *P. solenopsis*, four species of parasitoids emerged from this mealybug, two of them are new host records (Table 1).

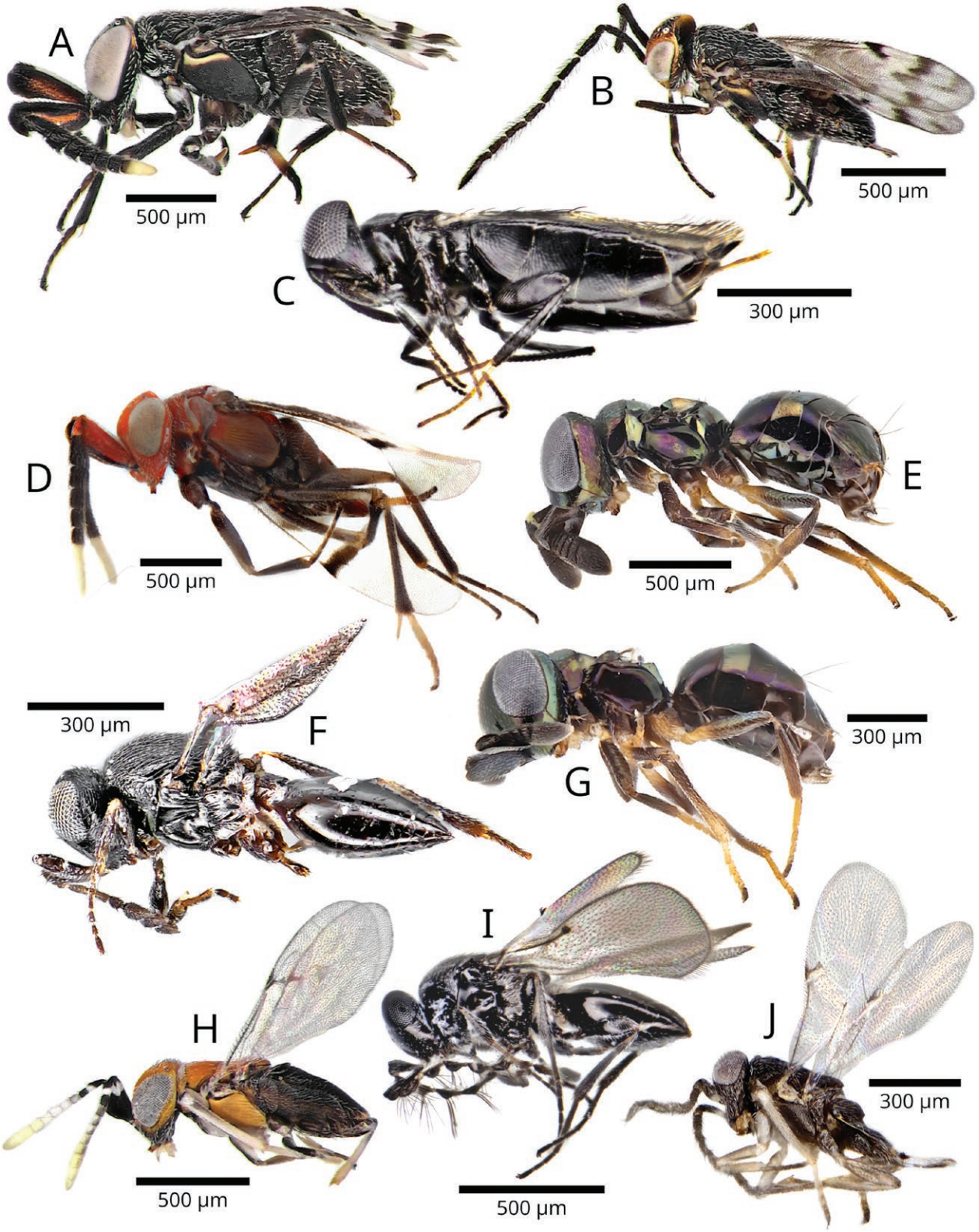

Figure 3. Parasitoids associated with mealybugs in protected agriculture in México. **A.** *Dicarnosis ripariensis* female; **B.** *D. ripariensis* male; **C.** *Chartocerus axillaris* female; **D.** *Anagyrus paralia* female; **E.** *Holcencyrtus osborni* female; **F.** *Allotropa* sp. female; **G.** *H. osborni* male; **H.** *Anagyrus tristis* female; **I.** *Allotropa* sp. male; **J.** *A. tristis* male.

These two parasitoid species had only been reported from the genus *Pseudococcus* (Noyes 2024).

In this work, 10 parasitoid species were recovered from mealybugs infesting vegetables in protected agriculture. Four species were associate with *P. solenopsis*, four with *P. solani* and four with *P. madeirensis*. Three of them are new records for México and six had a new host record. The other seven parasitoid species had already been reported,

for example: *D. ripariensis* and *A. tristis* were recorded from Estado de México in *P. madeirensis* (Lomeli et al. 2021; Acevedo-Alcalá et al. 2024a), while *E. americana* was recorded in a few states in México without knowing its host species (Trjapitzin et al. 2008). *Anagyrus paralia* was recorded in the northern, central-southern, and southeastern regions of México, but its host was not identified (Noyes 2000; Cancino and Blanco 2002; Trjapitzin et al. 2008). On the other hand, *A. arizonensis* and a species of the genus *Cheiloneurus* had been reported just recently on *P. solenopsis* in cotton crops of Mexicali, Baja California (González-Hernández et al. 2019). Also *H. osborni* was recorded in Veracruz, mainly on the genus *Dysmicoccus* Ferris (Trjapitzin et al. 2008).

We carried out sampling in greenhouses and net houses in different regions, dates and seasons of the year under commercial conditions. Many of the farmers carried out conventional pest management, others low insecticide use and some even organic production within their production systems, then it is very likely that management and control practices of mealybugs or other pest, have influenced the frequency and recovery of natural enemies at the sampling sites. Because of the biological and ecological diversity of a transition zone between the Nearctic and Neotropical regions, as is the case of México, it is advisable to increase exploration in different regions and seasons to potentially increase identification of natural enemies associated with mealybugs in protected agriculture and open field crops.

Conclusions

Four species of mealybugs were identified on vegetables grown in protected agriculture in 11 states of México. *Phenacoccus solenopsis*, *P. solani* and *P. madeirensis* were the predominant species on pepper and tomato; while *Ferrisia virgata* was only collected once from pepper. Eight species and two genera of parasitoids of the three most important mealybug species were recovered. Of these, three parasitoid species are first reported in México, and six now have a new host record. These findings contribute to a better understanding of the diversity and distribution of mealybugs and their natural enemies in protected agriculture systems. In addition, evaluating the basic biology of the parasitoids would be important to determine their potential as biological control agents, which could provide a solid foundation for the development and improvement of biological control programs in vegetable crops.

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