Armored scales (Hemiptera: Diaspididae) and their parasitoids on Hass avocado (Persea americana Miller) in two municipalities of the State of Mexico, Mexico

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Abstract

Armored scales and their parasitoids were collected and identified from avocado orchards in 2 municipalities of the state of Mexico; the population fluctuation and parasitism of the 3 most abundant armored scales also were determined. The armored scales species (Hemiptera: Diaspididae) identified were Hemiberlesia cyanophylli (Signoret), Davidsonaspis aquacaeae (Evans, Watson, & Miller), Diaspis nr. coccios (Lichtenstein), Hemiberlesia lataniae (Signoret), and Hemiberlesia rapax (Comstock); as well as the associated parasitoids Encarsia aurantii (Howard), Encarsia citrina (Craw), Encarsia gaonaee (Myartseva & Evans), Encarsia lounsburyi (Berlese & Paoli), Aphytis proclia (Walker), Coccobius averini (Myartseva), Coccobius juliae (Myartseva), Coccobius mariae (Myartseva) (all Hymenoptera: Aphelinidae), Signiphora falcata (Woolley & Dal Molin), Signiphora fax (Girault), Signiphora flavella (Girault), Signiphora mexicana (Ashmead) (all Hymenoptera: Signiphoridae), and Plagiomerus diaspidis (Crawford) (Hymenoptera: Encyrtidae). Some species from both groups constituted new distribution or host records in Mexico. Armored scale population densities generally increased per orchard and type of avocado tree structure from Oct to Apr, depending on the phenology of the avocado trees. The percentage of parasitism and adult parasitoid emergence varied according to their armored scale host population density. Most of the parasitoids emerged from armored scales collected from branches (82), followed by armored scales collected from fruits (59), and leaves (18).

Key Words: Hemiberlesia; Davidsonaspis; population fluctuation; parasitism; Aphelinidae; Signiphoridae

Resumen

Las escamas armadas (Hemiptera: Diaspididae) y sus parasitoides se colectaron de huertos de aguacate de dos municipios del Estado de México, además, de las tres escamas armadas más abundantes se determinó la fluctuación poblacional y parasitismo. Las especies de escamas armadas identificadas fueron: Hemiberlesia cyanophylli (Signoret), Davidsonaspis aquacaeae (Evans, Watson, & Miller), Diaspis c.a. coccios (Lichtenstein), Hemiberlesia lataniae (Signoret) y Hemiberlesia rapax (Comstock); así como los parasitoides Encarsia aurantii (Howard), Encarsia citrina (Craw), Encarsia gaonaee (Myartseva & Evans), Encarsia lounsburyi (Berlese & Paoli), Aphytis proclia (Walker), Coccobius averini (Myartseva), Coccobius juliae (Myartseva), Coccobius mariae (Myartseva) (todos Hymenoptera: Aphelinidae); Signiphora falcata (Woolley & Dal Molin), Signiphora fax (Girault), Signiphora flavella (Girault), Signiphora mexicana (Ashmead) (todos Hymenoptera: Signiphoridae) y Plagiomerus diaspidis (Crawford) (Hymenoptera: Encyrtidae). Adicionalmente, algunas especies de ambos grupos constituyen nuevos registros de distribución o nuevos hospedantes para México. Las densidades poblacionales de las escamas armadas aumentaron generalmente por huerto y tipo de estructura del árbol, en el periodo de octubre a abril, lo cual dependió de la fenología del cultivo de aguacate; mientras que, los porcentajes de parasitismo y de emergencia de los adultos parasitoides, variaron de acuerdo con el comportamiento de las poblaciones de sus escamas huéspedes. La mayor cantidad de parasitoides emergieron de escamas armadas colectadas en ramas (82), seguido de escamas armadas en frutos (59) y escamas armadas en hojas (18).

Palabras Clave: Hemiberlesia; Davidsonaspis; fluctuación poblacional; parasitismo; Aphelinidae; Signiphoridae

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yr, some armored scale species have begun to arise as economically important recurrent pests in several avocado orchards in the state of Mexico. Moreover, the presence of new species may represent a quarantine concern for various countries due to the possible introduction and establishment of these species and the damage they may cause (Evans & Dooley 2013). Armored scales often are efficiently regulated by natural enemies (Rosen 1973), especially parasitoids (Lázaro-Castellanos et al. 2012). In Mexico, except for the work done in Michoacán by Lázaro-Castellanos et al. (2012), there is not enough information on the natural enemies of armored scales on avocado and their potential use in biological control programs. The objectives of the present research were (1) to identify the species of armored scale insects and their parasitoids in commercial avocado plantings of 2 municipalities in the state of Mexico, and (2) to determine the population fluctuation of the most abundant armored scale species, as well as to obtain the percentage of parasitism in each of the armored scale species.

**Materials and Methods**

Four avocado orchards were selected in the municipalities of Coatepec Harinas and Villa Guerrero. Three orchards were planted with avocado cv. Hass and the other with cv. Hass-Jimenez at Salvador Sánchez Colín Foundation, Coatepec Harinas, Estado de México, Mexico (CICTAMEX, S.C.). The orchards were under conventional agronomic management, and each was geo-referenced (Table 1). In each orchard, 10 trees were selected randomly and marked with a yellow ribbon for monthly samplings. The host substrates evaluated were branches and fruits where the populations were constant during the sampling period. The samplings were conducted from May 2017 to Apr 2018, but on fruits the sampling was done from Jul 2017 to Apr 2018 since from May to Jun 2017, fruits were not present in the orchards.

From each selected tree, 10 branches around 20 cm long with leaves were cut randomly; if fruits were present, 10 were taken also. This material was placed in a brown paper bag (#16) with the respective identification code. Subsequently, the material was transported to the Fruit Pest Lab at Colegio de Postgraduados, Campus Montecillo, Texcoco, Estado de México, Mexico. From 4 branches randomly selected, a 5 cm subsample was taken; if fruits were available, 4 were taken. The selected material was checked with a stereoscopic microscope (American Optical Co., Buffalo, New York, USA) to separate armored scales species. In each armored scales species, the total number of specimens was counted for each developmental stage to record the percentage of parasitism in each of the armored scale species.

| Name of orchard | Geographical coordinates | Altitude (masl) | Municipality, community | Avocado variety |
|-----------------|--------------------------|-----------------|-------------------------|----------------|
| Papalote 1      | 18.938472°N, 99.72972°W | 2,320           | Villa Guerrero, Porfirio Díaz | Hass         |
| Cochisquila 1   | 18.910694°N, 99.75208°W | 2,144           | Coatepec Harinas, Cochisquila | Hass         |
| La Casita       | 18.927777°N, 99.81325°W | 2,230           | Coatepec Harinas, Ixtlahuaca de Villada | Hass |
| Bordo 2, CICTAMEX | 18.917472°N, 99.75930°W | 2,244           | Coatepec Harinas, Coatepec Harinas | Hass-Jimenez |

The following species of armored scales (Hemiptera: Diaspididae) were identified: *Hemiberlesia lataniae* (Signoret) [reference numbers CEAM-2017_18-M2Mx1, CEAM-2017_18-M7aMx1-2], *Hemiberlesia cyanophylli* (Signoret) [reference numbers CEAM-2017_18-M2Mx2-4, CEAM-2017_18-M7aMx3-5], *Davidosonapis aguacatae* (Evans, Watson, & Miller) [reference numbers CEAM-2017_18-M5Mx1-4, CEAM-2017_18-M10Mx1-4], *Hemiberlesia rapax* (Comstock) [reference number CEAM-2017_18-M5Mx5], and *Diaspis nr. coccis* (Lichtenstein) [reference number CEAM-2017_18-M10Mx5-8]. Armored scales *H. lataniae* and *H. cyanophylli* were collected from orchards Papalote 1 (Villa Guerrero) and Bordo 2 (Coatepec Harinas); *D. aguacatae* from orchards Cochisquila 1 and La Casita (Coatepec Harinas); *H. rapax* and *D. nr. coccis* were collected occasionally from orchards Cochisquila 1 and La Casita, respectively. Armored scales *H. lataniae*, *H. rapax*, *H. cyanophylli*, and *D. nr. coccis* were found associated with fruits, branch-

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**Results**

The temporal analysis of armored scales and associated parasitoids on avocado plantings was carried out in the 4 localities. A Kolmogorov-Smirnov test was performed to corroborate the normal distribution of population densities of armored scales and parasitoids. In addition, a Kruskal-Wallis test was used to compare armored scale populations on different tree substrates (branch or fruit). A linear regression was performed to test the relationship between the armored scale population density and their parasitoids. All data were analyzed using the program R vers. 3.4.0. (R CoreTeam 2015).

Climatological data from CONAGUA (Comisión Nacional del Agua: National Commission of Waters) were obtained for locations of Porfirio Díaz (Villa Guerrero), Cochisquila, Ixtlahuaca de Villada, and Coatepec Harinas (Coatepec Harinas) from 1981 to 2010 to analyze the possible effect of temperature and relative humidity on the population density of the armored scales and their natural enemies.
es, and leaves, whereas *D. aquacatae* was associated with fruits and branches. *Diapsis nr. coccoid* showed a higher population density on leaves, whereas the rest of the species did so on branches and fruits.

The parasitoids obtained from these armored scales on avocado belong to the Aphelinidae, Signiphoridae, and Encyrtidae families (Hymenoptera). From the first family, 8 species were identified: *Encarsia auranti* (Howard) [reference number CEAM-ECMA2017_18-Ea1-3], *Encarsia citrina* (Craw) [reference number CEAM-ECMA2017_18-Ec1-2], *Encarsia gaonae* (Myartseva & Evans) [reference number CEAM-ECMA2017_18-Eg1-3], *Encarsia lounsburyi* (Berlese & Paoli) [reference number CEAM-ECMA2017_18-Elou1-3], *Encarsia aurantii* (Walker) [reference number CEAM-ECMA2017_18-Eg1-3], *Encarsia lounsburyi* (Walker) [reference number CEAM-ECMA2017_18-Eg1-3], *Plagiomerus diaspidis* (Craw) [reference number CEAM-ECMA2017_18-Ec1-2], *Signiphora mexicana* (Ashmead) [reference number CEAM-ECMA2017_18-Smx1]; from Encyrtidae only *Plagiomerus diaspidis* (Crawford) was identified [reference numbers CEAM-ECMA2017_18-Pd1-2]. Information on geographical distribution and hosts of each parasitoid species also is included (Table 2).

The population fluctuation was studied only in the case of armored scales *D. aquacatae*, *H. cyanophylli*, and *H. lataniae*, because they were the most abundant scale species. In general, the population density of these armored scales decreased during the rainy period in the region from Jul to Sep 2017, except in the Papalote 1 orchard. In La Casita, Cochisquilla 1, and Papalote 1, armored scale population densities increased from Oct 2017 to Jan 2018, although in orchards Bordo 2 and Papalote 1, the highest scale density was observed in Feb and Mar 2018, respectively (Fig. 1). The Kolmogorov-Smirnov test showed that the population densities of the armored scales (*D. aquatic* = 0.39098; *p* < 2.961e-09) and parasitoids (*D. aquatic* = 0.75758; *p* = 0.005874; confidence: 99%) (Fig. 3). A positive correlation between the population density of armored scales and the percentage of parasitism was observed (R-squared: 0.4654; df = 97; *p* = 0.005874; confidence: 99%) (Fig. 3).

### Table 2. Armored scales, distribution, and abundance of parasitoid species in Hass avocado orchards of the State of Mexico, Mexico.

| Scale species          | Orchard and municipality | Parasitoid species (# specimens: # per sex) |
|------------------------|--------------------------|---------------------------------------------|
| *Hemiberlesia cyanophylli* | Papalote 1, Villa Guerrero | *Encarsia auranti* (26: 23♀, 3♂) |
|                        |                          | *Encarsia citrina* (7♀) |
|                        |                          | *Encarsia gaonae* (19: 13♀, 6♂) |
|                        |                          | *Coccobius averini* (4: 2♀, 2♂) |
|                        |                          | *Coccobius juliae* (4♀) |
|                        |                          | *Signiphora falcata* (2: 1♀, 1♂) |
|                        |                          | *Plagiomerus diaspidis* (1♂) |
|                        | Bordo 2, Coatepec Harinas | *Coccobius juliae* (1♂) |
|                        |                          | *Coccobius mariae* (1♀) |
|                        |                          | *Signiphora mexicana* (1♀) |
|                        |                          | *Plagiomerus diaspidis* (1♂) |
| *Davidsonaspis aquacatae* | Cochisquilla 1, Coatepec Harinas | *Encarsia auranti* (1♀) |
|                        |                          | *Coccobius averini* (2: 1♀, 1♂) |
|                        | La Casita, Coatepec Harinas | *Encarsia auranti* (1♀) |
|                        |                          | *Encarsia citrina* (6♀) |
|                        |                          | *Encarsia lounsburyi* (27) |
|                        |                          | *Aphytis proclia* (2♀) |
|                        |                          | *Coccobius averini* (3♂) |
|                        |                          | *Coccobius juliae* (2♂) |
|                        |                          | *Plagiomerus diaspidis* (1♂) |
| *Diapsis nr. coccoid* | La Casita, Coatepec Harinas | *Encarsia lounsburyi* (4♀) |
|                        |                          | *Coccobius juliae* (1♀) |
|                        |                          | *Coccobius mariae* (1♀) |
| *Hemiberlesia lataniae* | Papalote 1, Villa Guerrero | *Encarsia auranti* (5: 4♀, 1♂) |
|                        |                          | *Encarsia citrina* (2♀) |
|                        |                          | *Encarsia gaonae* (11: 9♀, 2♂) |
|                        |                          | *Encarsia lounsburyi* (1♀) |
|                        |                          | *Coccobius juliae* (2: 1♀, 1♂) |
|                        |                          | *Signiphora falcata* (1♀) |
|                        |                          | *Signiphora fax* (2♀) |
|                        | Bordo 2, Coatepec Harinas | *Coccobius averini* (4: 2♀, 2♂) |
|                        |                          | *Coccobius juliae* (2: 1♀, 1♂) |
|                        |                          | *Coccobius mariae* (1♀) |
|                        |                          | *Signiphora fax* (1♂) |
|                        |                          | *Signiphora flavella* (3♀) |
|                        |                          | *Plagiomerus diaspidis* (2♂) |
|                        |                          | *Encyrtidae sp. 1* (1♀) |
|                        |                          | *Encyrtidae sp. 2* (1♀) |
| *Hemiberlesia rapax* | Cochisquilla 1, Coatepec Harinas | *Plagiomerus diaspidis* (1♀) |
Fig. 1. Mean armored scales in 4 Hass avocado orchards in Coatepec Harinas and Villa Guerrero, Estado de Mexico, Mexico, from May 2017 to Apr 2018.

Fig. 2. Percentage of parasitism in armored scale in 4 Hass avocado orchards in Coatepec Harinas and Villa Guerrero, Estado de Mexico, Mexico, from May 2017 to Apr 2018.
The Kruskal-Wallis test ($\chi^2 = 17.161; \text{df} = 2; \text{p} = 0.0001878$) indicated differences in the distribution of 2 species of armored scales; *D. aguacatae* was more abundant on branches whereas *H. cyanophylli* was more abundant on fruits (Fig. 4).

In orchard Papalote 1 (Villa Guerrero), *H. cyanophylli* was present on branches with very low population densities from 0.004 to 0.180 armored scales per branch. The peaks of population densities were observed in the months of May, Aug, Oct, and Dec 2017, and Apr 2018 (Fig. 5a), but the most constant populations were observed in the period from May to Aug 2017. Regarding parasitism, the highest percentages were reached in Jun 2017, and from Mar to Apr 2018, with 30, 23, and 29%, respectively (Fig. 5a). In the remaining mo, percentage of parasitism oscillated between 8 and 16%.

In the case of *H. lataniae*, the densities also were lower, with a mean of 0.15 to 0.80 armored scales per branch. The highest peaks were observed in Oct and Nov 2017 with densities near 0.5 armored scales per branch, and in Jan and Apr 2018, with densities of 0.6 and 0.8 armored scales per branch, respectively (Fig. 5b). Parasitism, in this case, was greater in Jun 2017 and Apr 2018, with 31 and 38%, respectively. In the remaining mo, the percentages ranged between 8 and 23% (Fig. 5b). On fruits, *H. cyanophylli* showed mean population densities from 1.15 to 5.14 armored scales per fruit, with peaks in Jan and Mar 2018 with densities from 3 to 5 armored scales per fruit (Fig. 5c). The parasitism of *H. cyanophylli* reached its highest levels in Oct 2017 and Apr 2018 with levels of 28 and 48%, respectively (Fig. 5c), whereas in the remaining mo it ranged between 4 and 22%. With regard to *H. lataniae*, the population densities were even lower, where they oscillated between 0.004 and 1.17 armored scales per fruit, and in some mo, they were almost imperceptible (Fig. 5d); however, the highest
Fig. 5. Mean *Hemiberlesia cyanophylli* and *Hemiberlesia lataniae* armored scales and percentage of parasitism on branches (a, b) and fruits (c, d) on Hass avocado in the Papalote 1 orchard (Villa Guerrero) from May 2017 to Apr 2018.
peaks were observed in Jul 2017 and Feb 2018. Parasitism on fruits reached its highest peak in Feb 2018 with 52% (Fig. 5d).

In orchard Cochisquila 1 (Coatepec Harinas), D. aguacatae was present on branches at mean population densities between 0.6 and 2.9 armored scales per branch, reaching their highest peaks in May 2017 and Jan 2018 (Fig. 6a). Parasitism was greater in Jul and Sep 2017 with levels of 16 and 11%, respectively. The remaining mo had percentage parasitism between 1 and 5% (Fig. 6a). On fruits, D. aguacatae registered mean population densities even lower, between 0.06 and 0.82 armored scales per fruit, being the highest in Jul 2017 and Apr 2018 (Fig. 6c) with densities over 0.6 armored scales per fruit. Parasitism reached its highest peak in Aug and Dec 2017, and Apr 2018 with 8, 8, and 19%, respectively; in the remaining mo, it oscillated between 0 and 6% (Fig. 6c).

In orchard La Casita (Coatepec Harinas) on branches, D. aguacatae showed mean population densities ranging from 0.75 and 2.55 armored scales per branch. The highest population density peaks were in May, Oct, and Dec 2017, and Feb and Apr 2018, with around 2.5 mean armored scales per branch (Fig. 6b). Parasitism reached its highest levels in Nov 2017 and Feb 2018 with 11 and 12%, respectively, and in the remaining mo it was between 3 and 9%. On fruits, D. aguacatae showed mean densities ranging from 0.08 to 2.05 armored scales per fruit. The highest density was reached in Jan 2018 with over 2.0 armored scales per fruit (Fig. 6d). Parasitism was highest also in the mo of Jan 2018 with 11% whereas in the remaining mo it was between 0 and 5% (Fig. 6d).

In orchard Bordo 2 (Coatepec Harinas) on branches, H. cyanophylli showed very low population densities between 0.008 and 0.09 mean armored scales per branch. The highest density was registered in May 2017 and Mar 2018 (Fig. 7a). Parasitism was registered only in 4 mo during May 2017 and Apr 2018 with the level of 13 and 10%, respectively, and in the remaining mo it was between 4 and 9% (Fig. 7a). In the case of H. lataniae, the population densities ranged between 0.008 and 0.14 mean armored scales per branch with the highest peaks in Jun 2017 and Jan and Apr 2018 (Fig. 7b). Parasitism showed its highest levels in Jul 2017 and Feb 2018 with 20 and 27%, respectively. In the remaining months, the levels ranged from 0 to 16% (Fig. 7b). On fruits, H. cyanophylli showed mean population densities ranging between 0.008 and 0.45 armored scales per fruit, reaching its highest density in the mo of Mar and Apr 2018 (Fig. 7c). Parasitism was registered in the period from Dec 2017 to Apr 2018 reaching its highest peak in Jan 2018 at 33%. In the remaining mo, parasitism ranged between 7 and 20% (Fig. 7c). Hemitberlesia lataniae showed population densities between 0.004 and 0.12 mean armored scales per fruit. The highest densities were in the mo from Feb to Apr 2018 (Fig. 7d), whereas no presence of the species was detected in Aug 2017. Parasitism in this species was present only in the mo of Jan, Mar, and Apr 2018 with 17, 15, and 11%, respectively (Fig. 7d).

From the armored scales material collected and kept in the laboratory, 159 parasitoid specimens emerged; 88 came from Papalote 1 orchard, 6 from Cochisquila 1, 48 from La Casita, and 17 from Bordo 2 (Table 2). The numbers of parasitoids obtained per avocado tree substrates were 18 on leaves, 59 on fruits, and 82 on branches. The most abundant parasitoid species were E. auranti with 33 specimens associated with armored scales H. cyanophylli, D. aguacatae, and H. lataniae; E. lounsburyi with 32 specimens associated with armored scales D. aguacatae, D. nr. cocois, and H. lataniae; E. gaona with 27 specimens associated with armored scales H. cyanophylli and H. lataniae; E. citrino with 15 specimens associated with armored scales H. cyanophylli, D. aguacatae, and H. lataniae; C. jullae with 14 specimens associated with armored scales H. cyanophylli, D. aguacatae, D. nr. cocois, and H. lataniae; and the parasitoid C. averini with 13 specimens associated with armored scales H. cyanophylli, D. aguacatae, and H. lataniae. The rest of the parasitoid species were obtained in numbers from 1 to 6 specimens. The Encyrtidae Plagiomerus diaspidis was the only species obtained from the 5 armored scale species, although with few specimens (6) (Table 2). The mo in which the greatest number of parasitoids emerged were from Oct 2017 to Mar 2018, with a decrease in Apr and increasing in May 2018 (Table 3). The development stages from which the parasitoid species emerged were, from greatest to lowest, adult female, nymph 3, males, and nymph 2; on the last one, 3 species of Encarsia were obtained (Table 4).

**Discussion**

From the 5 species of armored scales identified in the present study, 4 have been reported previously associated with avocado orchards in Mexico. González and Atkinson (1984) reported H. lataniae and H. rapax in some Rosaceae species and on avocado in Texcoco and Villa del Carbón, in Estado de Mexico. Also, Lázaro-Castellanos et al. (2012) reported H. lataniae, H. rapax, and D. aguacatae present in Hass avocado in the municipalities of Ario de Rosales, Nuevo San Juan Parangacutiro, Los Reyes, Peribán, Salvador Escalante, Tacámbaro, Tingambato, and Ziracuaretiro, Michoacán. González and Atkinson (1984) registered Diaspis nr. cocois in the central region of Mexico, although without specifying its geographical distribution. This latter species also has been collected from Hass avocado and cv. Mexicano (native) in several municipalities in Michoacán (González-Hernández, Fitosanidad-Entomología y Acarología, Colegio de Postgraduados, personal communication). Meanwhile, Morse et al. (2009) mention that D. nr. cocois could be misidentified, because it has been detected only in palm trees. This scale was determined as D. nr. cocois based on the middle lobules (L1) forming a median notch in the pygidium, lack of ear-like lateral prothoracic protuberances, and lack of submedian dorsal micro pores in segments VI and VII of the pygidium. According to the descriptions by Ferris (1954), McKenzie (1956), and Boratynski (1968), these morphological characters are very similar to D. cocois. Also, it is possible that it could be a new species, and given its morphological likeness to the coconut armored scales, it has been named Diaspis nr. cocois until it can be correctly determined. With regard to H. cyanophylli, the second author of this paper has collected the species from Hass avocado in orchards in the municipalities of Tancitaro, Zitácuaro, and Uruapan, Michoacán (González-Hernández, Fitosanidad-Entomología y Acarología, Colegio de Postgraduados, personal communication). In the present study, D. aguacate represents the first record of the species in Estado de Mexico, as well as a new record of national distribution, because it had previously been reported only in Hass avocado in Michoacán, where it was considered endemic (Evans et al. 2009; Lázaro-Castellanos et al. 2012).

The 4 Encarsia species determined in the present research have been reported in Mexico as parasitoids of several species of armored scales (Myartseva et al. 2016b). Myartseva and Evans (2007) indicate that in Mexico, E. auranti has been detected on Chrysomphalus aonidum (L.) and Aonidiella auranti Maskell (both Hemiptera: Diaspididae) in the states of Baja California Sur, Tamaulipas, and Jalisco. This species was introduced successfully to Mexico to control Ch. aonidum in 1949 to 1950. Moreover, Encarsia species have been reported around the world attacking other species of armored scales of Aonidiella, Aspidiotus, Chrysomphalus, Diaspidiotus, Hemitberlesia, Insulaspis, Lepidosaphes, Melanaspis, Parlatoria, Pinnaspis, Pseudalacaspis, Parlatoria, and Quadraspidiotus (now Diaspidiotus) (all Hemiptera: Diaspididae) among others (Myartseva & Evans 2007). Encarsia citrina has been reported attacking D. aguacatae, H. lataniae, and H. rapax in Hass
Fig. 6. Mean *Davidsonaspis aguacatae* armored scale on branches and fruits of Hass avocado and percentage of parasitism in Coquisquilla 1 (a, c), and La Casita (b, d) orchards (Coatepec Harinas) from Jul 2017 to Apr 2018.
avocado in Michoacán, Mexico, and was proposed as the parasitoid species with the greatest potential as a biological control agent of these armored scales in Hass avocado orchards in Michoacán, Mexico (Lázaro-Castellanos et al. 2012). *Encarsia gaonae* has been obtained from *Pinnaspis strachani* (Cooley) (Hemiptera: Diaspididae) associated with *Amyris madrensis* Watson (Rutaceae) in Ciudad Victoria, Tamaulipas, Mexico (Myartseva & Evans 2007). *Encarsia lounsburyi* is a cosmopolitan species very similar to *E. citrina*, although with some morphological differences that allow one to separate them (Myartseva & González-Hernández 2007). *Encarsia lounsburyi* has been found as a parasite of *D. aguacatae* on Hass avocado fruits in shipments from Michoacán, Mexico, destined to Florida, USA (Stocks & Evans 2017).

In the present study, all 4 parasitoid species present new geographical distribution records in Mexico. Furthermore, *E. auranti* presents 3 new host records in Mexico: *H. cyanophylli*, *D. aguacatae*, and *H. lataniae*. Meanwhile, *E. gaonae* has 2 new host records: *H. cyanophylli* and *H. lataniae*. In the case of *E. lounsburyi*, it has 2 new host records: *D. nr. cocos* and *H. lataniae*.

*Aphytis proclia* has a Holarctic origin and is considered almost cosmopolitan given its wide distribution around the world. In Mexico, it has been obtained from *Ch. aonidum* and *Ch. dyctiospermi* on citrus fruits in the state of Veracruz, Mexico. Around the world, it has been registered as a parasite of over 60 species of Diaspididae (Myartseva et al. 2010). The present record of *D. aguacatae* represents a new geographical distribution for the country and as a new host.

The species of *Coccobius* generally are parasites of armored scales in several regions around the world (Prinsloo 1995; Evans & Pedata 1997; Myartseva 2015); some even have been introduced to different countries to control economically important armored scales (Wang et al. 2014; Myartseva 2015; Myartseva et al. 2016a). They are primary endo-parasitoids and the males are ecto- or endohyper- parasitoids of females in the same species of other parasitoids (Prinsloo 1995). Seven species are reported in Mexico, such as *C. averini*, *C. juliae*, and *C. mariae*, detected at Las Barracas, Baja California Sur, Mexico (Myartseva 2015; Myartseva et al. 2016a). In the present study, a new geographical distribution is reported for the 3 parasitoid species, as well as new host registries for *C. averini*, being a parasite of *H. cyanophylli*, *D. aguacatae*, and *H. lataniae*. *Coccobius juliae* is reported being a parasite of armored scales *H. cyanophylli*, *D. aguacatae*, *D. nr. cocos*, and *H. lataniae*, and *C. mariae* of armored scales *H. cyanophylli*, *D. nr. cocos*, and *H. lataniae* (Myartseva 2015; Myartseva et al. 2016a).

The 4 species of *Signiphora* registered in this paper have been reported as hyperparasitoids of armored scales in Mexico and other countries. Other species in this genus are parasitoids or hyperpara-

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### Table 3. Months of the emergence of the most abundant parasitoids associated to armored scales in Hass avocados in the State of Mexico, Mexico, from Jun 2017 to May 2018.

| Date      | *E. auranti* | *E. citrina* | *E. gaonae* | *E. lounsburyi* | *C. averini* | *C. juliae* | *P. diaspidis* |
|-----------|-------------|--------------|-------------|-----------------|--------------|-------------|---------------|
| Jun 17    | 2           | 0            | 2           | 0               | 0            | 0           | 0             |
| Jul 17    | 2           | 0            | 0           | 0               | 3            | 1           | 1             |
| Aug 17    | 0           | 0            | 0           | 0               | 0            | 0           | 0             |
| Sep 17    | 7           | 0            | 0           | 0               | 2            | 0           | 0             |
| Oct 17    | 1           | 2            | 0           | 7               | 0            | 1           | 0             |
| Nov 17    | 3           | 2            | 4           | 14              | 2            | 1           | 0             |
| Dec 17    | 3           | 4            | 3           | 3               | 0            | 3           | 0             |
| Jan 18    | 6           | 4            | 3           | 5               | 0            | 2           | 2             |
| Feb 18    | 1           | 3            | 3           | 3               | 0            | 0           | 1             |
| Mar 18    | 3           | 0            | 9           | 0               | 2            | 2           | 1             |
| Apr 18    | 1           | 0            | 1           | 0               | 2            | 0           | 1             |
| May 18    | 4           | 0            | 5           | 0               | 2            | 4           | 0             |
| Total     | 33          | 15           | 30          | 32              | 13           | 14          | 6             |

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### Table 4. Parasitoid emergence by the state of development of armored scales in Hass avocados in the State of Mexico, Mexico, from Jun 2017 to May 2018.

| Species              | N2* | N3* | Adult females | Males | Total |
|----------------------|-----|-----|---------------|-------|-------|
| *Encarsia auranti*   | 1   | 14  | 10            | 8     | 33    |
| *Encarsia citrina*   | 2   | 3   | 5             | 5     | 15    |
| *Encarsia gaonae*    | 0   | 9   | 16            | 5     | 30    |
| *Encarsia lounsburyi*| 10  | 5   | 4             | 13    | 32    |
| *Aphytis proclia*    | 0   | 3   | 9             | 1     | 13    |
| *Coccobius averini*  | 0   | 3   | 11            | 0     | 14    |
| *Coccobius juliae*   | 0   | 0   | 2             | 0     | 2     |
| *Signiphora falcata* | 0   | 0   | 1             | 2     | 3     |
| *Signiphora fax*     | 0   | 1   | 0             | 2     | 3     |
| *Signiphora flavella*| 0   | 1   | 2             | 0     | 3     |
| *Signiphora mexicana*| 0   | 0   | 1             | 0     | 1     |
| *Plagiomerus diaspidis* | 0  | 0   | 5             | 1     | 6     |
| *Encyrtidae sp. 1*   | 0   | 0   | 1             | 0     | 1     |
| *Encyrtidae sp. 2*   | 0   | 0   | 1             | 0     | 1     |
| Total                | 13  | 41  | 70            | 38    | 159   |

*N2 = Nymph second instar; N3 = Nymph third instar.
sitoids of armored scales and mealybugs (Ramírez-Ahuja et al. 2015; Woolley & Dal Molin 2017). In Mexico, *S. falcata* has been obtained from some species of Diaspididae in the states of Michoacán, Guanajuato, and Nuevo León (in the municipalities of Monterrey and Linares). In Nuevo León, *S. falcata* was reported parasitizing the armored scale *Mycetaspis personata* (Comstock) (Hemiptera: Diaspididae) on avocado. The male of this species is considered to be a hyperparasitoid. Also, in Brazil, it has been obtained from armored scale *Pseudospondylus trilobitiformis* (Green) (Hemiptera: Diaspididae) (Woolley & Dal Molin 2017). *Signiphora fax* Girault (Hymenoptera: Signiphoridae) has been recorded as a parasitoid of *A. auranti, H. lataniae, L. beckii, Aonidomytilus spinosai* (Porter), *Aspidiotus spp., Chrysomphalus spp., Chionaspis* spp. (all Hemiptera: Diaspididae), and the Aleyrodidae *Aleurothrixus floccosus* (Maskell) (Hemiptera: Aleyrodidae). It is believed that *S. fax* also is a hyperparasitoid of *Aphytis lepidosaphes* (Compere) (Hymenoptera: Aphelinidae). In Mexico, it has been registered, but with no information on the host or its distribution (Woolley & Dal Molin 2017). *Signiphora flavella* commonly is a parasite of armored scales and mealybugs (Ramírez-Ahuja et al. 2015; Woolley & Dal Molin 2017). *Signiphora flavella* commonly is a parasite of armored scales and mealybugs (Ramírez-Ahuja et al. 2015; Woolley & Dal Molin 2017). *Signiphora flavella* commonly is a parasite of armored scales and mealybugs (Ramírez-Ahuja et al. 2015; Woolley & Dal Molin 2017). *Signiphora flavella* commonly is a parasite of armored scales and mealybugs (Ramírez-Ahuja et al. 2015; Woolley & Dal Molin 2017).
and has a cosmopolitan distribution (Woolley & Dal Molin 2017). It is a primary parasitoid of *H. lataniae* and *H. rapax* in California, USA. Meanwhile, in Mexico it has been collected from armored scales in citrus fruits in Xochocotlan, Oaxaca; in *Aspidiotus* sp. feeding on *Myrtus* sp. (Myrtaceae) in Orizaba, Veracruz, and on avocado in Uruapan, Michoacán (Ramírez-Ahuja et al. 2015). Around the world, *S. flavella* also has been obtained from species of *Aonidiella*, *Aspidiotus*, *Aulacaspis*, *Lepidosaphes*, *Hemiberlesia*, *Parlatoria*, and *Diaspidiotus* (Woolley & Dal Molin 2017). *Signiphora mexicana* has been registered for Mexico in the state of San Luis Potosí and Xochipala, Guerrero, and is a parasitoid of the *A. nerii*, and a soft scale (without specifying the species) on *Opuntia* (Cactaceae). In other countries, it attacks also species of *Chrysosphalus*, the soft scales *Pulvinaria* and *Coccus* (Hemiptera: Coccidae) (Ramírez-Ahuja et al. 2015). In the present study, all 4 Signiphoridae species represent new distribution in the state of Mexico, as well as the new host in Mexico, because *S. falcata* was detected as a parasitoid of *H. cyanophylli* and *H. lataniae*. Meanwhile, *S. fax* is a new record on *H. lataniae*, as well as *S. flavella* on *H. lataniae*, and *S. mexicana* on *H. cyanophylli*.

The encyrtid *Plagiomerus diaspidis* already has been reported associated with armored scales on avocado in Michoacán, Mexico (Lázaro-Castellanos et al. 2012). The species of this family develop as endo-parasitoids of armored scales. *Plagiomerus diaspidis* is a new distribution record for Estado de México, Mexico, as well as 3 new host registries, because it is a parasitoid of *H. cyanophylli*, *D. aguacatae*, and *H. rapax*.

Regarding the population fluctuation of armored scales, *D. aguacatae* showed greater population growth on avocado branches during the period from Oct 2017 to Jun 2018, whereas on fruits it was from Oct 2017 to Apr 2018. In the latter case, the difference is because, after Apr there are no more large fruits due to harvest. Additionally, *D. aguacatae* showed a higher mean population density on branches than on fruits (Fig. 5). The *D. aguacatae* populations increased during this period (Oct–Jun), when the mean temperatures oscillated between 13 and 17.8 °C, in Cochisquila and Ixtlahuaca de Villada (Coatepec Harinas) (CONAGUA 2018), and with mo when rainfall was the lowest, as in Oct when it fell from 98.2 to 68.3 mm per mo, and in Dec it fell from 12.0 to 7.5 mm. On the other hand, in mo with greater rainfall, the armored scales populations decreased perceptively (CONAGUA 2018). According to McClure (1990), some factors like temperature or humidity may affect the survival and spread of armored scales after the establishment of the crawler.

In some cases, such as in the orchard Papalote 1, *H. cyanophylli* showed its highest densities on fruits from Oct 2017 to Apr 2018 (Fig. 5a, c) when the mean temperatures oscillated between 12 and 17.5 °C in the localities of Porfrío Díaz (Villa Guerrero) and Coatepec Harinas (CONAGUA 2018). Since Oct, rainfall had decreased but increased considerably in Jun, thus the population fluctuation of *H. cyanophylli* was similar to that of *D. aguacatae*, with a decline in mo with greater rainfall. *Hemiberlesia cyanophylli* is found occasionally in great numbers on branches; its populations increased from Mar to Aug 2017, mo when the mean temperatures were higher, between 15.2 and 17.8 °C. The greatest rainfall of the yr was registered during the same period (Jun to Aug) (CONAGUA 2018).

*Hemiberlesia lataniae* was present in the same orchards as *H. cyanophylli* and their population on branches and fruits had similar densities (Fig. 5). On branches, occasionally it was the species with the highest population density, as in the case of the Papalote 1 orchard. In general, the *H. lataniae* population increased from Oct 2017 to Apr 2018, making its behavior similar to those of other armored scale species. On the other hand, it was occasionally the species with the lowest population density on fruits, as in the orchard Papalote 1 (Fig. 5d). This armored scale population generally increased from Jan to Apr, with mean temperatures from 12.1 to 17.5 °C and monthly rainfall of 10.6 to 30.7 mm (CONAGUA 2018). Both species, *H. lataniae* and *H. cyanophylli*, shared distribution on the tree structures, although they showed differences in the behavior of their population densities per tree substrates. McClure (1990) mentions that when 2 or more Diaspididae species share the same host, they can occupy different parts of the plant to avoid interspecific competition, besides temporal distribution where a species increases its populations in the warmer or colder mo.

The species of *Encarsia* were the most abundant armored scale parasitoids, followed by the *Coccobius* species. In this regard, Heraty et al. (2008) mentioned that species of *Encarsia* are some of the most exploited groups for the control of armored scales in agricultural environments besides being the largest and most diverse genus of Aphelinidae, with species specialized in attacking armored scales. Moreover, in many of the species of *Encarsia*, the males act as hyperparasitoids of their own females or others in the same genus, although this hyperparasitism characteristic also is shared by many species of *Coccobius* (Prinsloo 1995) and *Signiphora* (Woolley & Dal Molin 2017), as well as some Encyrtidae species (Noyes et al. 1997), which are parasites that may regulate armored scales populations. *Encarsia auratelli*, *E. citrina*, and *E. loumburyi* are documented to have been introduced into Mexico in classical biological control programs to manage armored scales (Myartseva & Evans 2008). In the present study, the first 2 showed greater distribution and host diversity, whereas *E. loumburyi* showed a preference for *D. aguacatae* (Table 2). On the other hand, *E. citrina* showed a lower density on the armored scales with the greatest abundance in the orchards. This agrees partially with Lázaro-Castellanos et al. (2012) for Michoacán, where it was detected as a parasitoid associated with *H. lataniae*, *D. aguacatae*, and *H. rapax*, present in Hass avocado orchards, and it was also the parasitoid species with the greatest abundance and distribution.

In the present study, *E. auratelli* was the most abundant and most distributed species. In Egypt, *E. auratelli* is considered one of the main regulatory agents of this group of insects (Abd-Rabou et al. 2014). *Encarsia gaona* was reported by Myartseva and Evans (2007) as having a limited distribution and host range in Mexico. *Encarsia gaona* is reported for the first time being associated with 2 species of armored scales on avocado.

The species of *Coccobius* with the greatest density and distribution in the orchard Bordo 2 in Coatepec Harinas were *C. averini* and *C. juilae*, which represent new distribution and host records for these species, although Myartseva et al. (2016a) reported both of these species from Baja California Sur, Mexico, but without host records. *Coccobius* is a medium-sized genus in the number of species of Aphelinidae, most of which are reported as specialized parasitoids in scale insects (Evans & Pedata 1997). Moreover, they are highly appreciated in biological control programs to manage armored scales in Asia, especially in China, where *Coccobius azumai* (Tachikawa) (Hymenoptera: Aphelinidae) was successfully introduced to control *Hemiberlesia pitysophila* (Takagi) (Hemiptera: Diaspididae), an important species in pine trees (Wang et al. 2014). All parasitoids obtained were principally armored scale adult females and third instar nymphs (N3), although there were some species that attacked second instar nymphs (N2). *Encarsia citrina* attack females from N2 individuals to adults and males from N2 individuals to pupa (Lázaro-Castellanos et al. 2012), and it has been reported that according to the temperature, it can show a certain preference for younger development stages (Bayoumy et al. 2013). Although *E. loumburyi* is a parasite of all developmental stages, it was commonly detected in N2 individuals; moreover, this species is morphologically very close to *E. citrina* (Myartseva & González-Hernández 2007), and
they are found parasitizing the same group of species (Myartseva & Evans 2007); therefore, it is possible that they share certain attack habits, as happens in closely related species (Heraty et al. 2008). In the present study, both species also were present in the same period of the yr (Table 3), although with different distribution and abundance (Table 2). Encarsia auranti for prefers the more developed instars of the host (adults and third instar); on only 1 occasion was it obtained from an N2.

The population density of the most frequently detected parasitoids (Fig. 2) in the Estado de México showed a clear dependence on the density of their host (Fig. 1), which is associated with a density-de
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