

**DIVERSITY AND DISTRIBUTION OF PARASITIDS OF
ANTHONOMUS EUGENII (COLEOPTERA: CURCULIONIDAE)
 FROM MEXICO AND PROSPECTS FOR BIOLOGICAL CONTROL**

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ABSTRACT

A survey of parasitoids of the pepper weevil (*Anthonomus eugenii* Cano), one of the most important pests of peppers in North America, was conducted in Mexico as part of a search for biological control agents of this pest. Surveys were conducted in different years on the Pacific and Atlantic Coasts in Mexico. We recovered parasitoid species belonging to 7 genera: *Triaspis eugenii* Wharton & López-Martínez, *Urosigalphus* sp., *Bracon* spp.; *Catolaccus hunteri* Crawford; *Eurytoma* spp.; *Eupelmus* sp.; and *Ceratoneura* sp. The latter species might be a newly recorded genus for this pest. *Catolaccus hunteri*, *T. eugenii*, and *Urosigalphus* sp. represented 96% of all recovered specimens. *Triaspis eugenii* was collected only in Nayarit, and *Urosigalphus* sp. predominated in Oaxaca; both locations are on the Pacific Coast. *Catolaccus hunteri* was present at every sample site. The biology of the braconids *T. eugenii* and *Urosigalphus* sp. would seem to make them best suited for biological control of pepper weevil due to their presumed host specificity and habit of attacking the host egg.

Key Words: *Capsicum* spp. pepper weevil, biological control, native natural enemies

RESUMEN

Como parte de una búsqueda de agentes de control biológico del picudo del chile (*Anthonomus eugenii* Cano), una de las plagas más importantes de este cultivo en Norteamérica, se realizaron colectas de parasitoides de esta plaga en México. Durante varios años se colectó material de las costas del Pacífico y del Atlántico, y se encontraron varias especies pertenecientes a siete géneros: *Triaspis eugenii* Wharton & López-Martínez, *Urosigalphus* sp., *Bracon* spp.; *Catolaccus hunteri* Crawford; *Eurytoma* spp.; *Eupelmus* sp. y *Ceratoneura* sp. De estos géneros sólo el último se reporta por primera vez para esta plaga. *Catolaccus hunteri*, *T. eugenii*, y *Urosigalphus* sp. representaron 96% del material colectado. *Triaspis eugenii* se colectó sólo en Nayarit, y *Urosigalphus* sp. predominó en Oaxaca, ambas localidades en la costa del Pacífico. *C. hunteri* se encontró en cualquier sitio de colecta. Parece ser que la biología de los bráconidos *T. eugenii* y *Urosigalphus* sp. podría ofrecer algunas ventajas para el control biológico del picudo del chile debido a su particular hábito de atacar el huevo del huésped y presumiblemente a su especificidad.

Translation provided by the authors.

The pepper weevil, *Anthonomus eugenii* Cano (Coleoptera: Curculionidae), was originally described from Guanajuato, Central Mexico, in 1894 (Cano & Alcacio 1894) and soon afterward (1904) was reported in the United States (Walker 1905). In both cases, attention was drawn to this insect because of damage observed on cultivated pepper (*Capsicum* spp.). Presently, the importance of this pest on peppers has been reported from some Caribbean islands, Central America, Mexico, the southern United States, and Hawaii (Elmore et al. 1934; Velasco 1969; Burke & Woodruff 1980;

Abreu & Cruz 1985; Andrews et al. 1986; Riley & King 1994; Coto 1996; Arcos et al. 1998).

The pepper weevil feeds and develops on several species of Solanaceae; however, it is a pest only on *Capsicum* spp. (Elmore et al. 1934; Wilson 1986; Patrock & Schuster 1992). Adults feed on buds, flowers, fruits, and even young foliage; larvae feed and develop completely inside floral buds and immature fruits. Premature abscission is a consequence of feeding and development inside buds and fruits, resulting in loss of production (Cano & Alcacio 1894; Walker 1905; Pratt 1907;

Elmore et al. 1934). Because all immature stages are protected within the fruits, insecticides can only target adults, and therefore, may not prevent insect damage. Fruit loss can reach 30 to 90% of the yield if treatment is not implemented (Campbell 1924; Elmore et al. 1934; Goff & Wilson 1937; Velasco 1969; Genung & Ozaki 1972; Riley & Sparks 1995).

A hundred years after the first report in Mexico and introduction into the United States, management practices against this pest are a combination of cultural and chemical control (Walker 1905; Elmore et al. 1934; Riley & King 1994). Biological control has not been considered an option, possibly because natural enemies of pepper weevil are poorly known. In the United States where this pest is not native, only 2 ant species (*Solenopsis geminata* F., *Tetramonium guinense* F.), 3 pteromalids (*Catolaccus hunteri* Crawford, *C. incertus* Ashmead, and *Habrocytus piercei* Crawford), and a braconid (*Bracon mellitor* Say) have thus far been identified (Pratt 1907; Pierce et al. 1912; Cross & Chesnut 1971; Wilson 1986). However, these natural enemies are not specific and are not thought to play an important role in the control of the pepper weevil (Pratt 1907; Elmore et al. 1934; Elmore & Campbell 1954; Genung & Ozaki 1972). A eupelmid (*Eupelmus cushmani* Crawford), a pteromalid (*C. hunteri*), and a braconid (*Triaspis vestitida* Viereck) were released in the U.S. as part of 2 unsuccessful attempts at classical biological control of pepper weevil before 1950 (Clausen 1978). These 3 parasitoid species had been obtained from biological control programs against the boll weevil (*Anthonomus grandis* Boheman). No additional attempts have been made to introduce natural enemies of this pest in the United States until recently (Toapanta 2001; Rodríguez-Leyva 2006).

Central and southern Mexico have been suggested as a possible center of origin and domestication of *Capsicum annuum* L. (Vavilov 1951; MacNeish 1964; Pickersgill & Heiser 1971; Eshbaugh 1976; Loaiza-Figueroa et al. 1989) and consequently, of the pepper weevil and its parasitoids. However, the only published survey of native parasitoids of the pepper weevil from Mexico was conducted recently in the state of Nayarit on the Mexican Pacific Coast (Mariscal et al. 1998). These authors found 4 species of Braconidae, 2 species of Pteromalidae, and 1 each of Eulophidae, Eupelmidae, and Eurytomidae. That report, and a complementary survey of the same area made by Toapanta (2001), indicated that *Triaspis eugeni* Wharton and López-Martínez (Hymenoptera: Braconidae) (Wharton & López-Martínez 2000) was the most abundant parasitoid of pepper weevil in Nayarit. Here we include additional surveys of Nayarit and other locations in Mexico, in addition to some unpublished Mexican references referring to natural enemies of this pest, with the objective of providing a better understanding of diversity and distribution of pepper weevil parasitoids in the region of likely origin of both *C. annuum* and the pepper weevil.

MATERIALS AND METHODS

Ten surveys were conducted on pepper production regions in Mexico between 1995 and 2003 (Table 1). Pepper fruits were collected from the Pacific and Gulf Coast of Mexico that exhibited signs of pepper weevil damage including presence of feeding and/or oviposition punctures. Fruits were collected from plants and/or those on the ground, usually in abandoned crops where infestation was high and insecticides no longer used. Different varieties

TABLE 1. SURVEY OF PEPPER WEEVIL PARASITIDS CONDUCTED BETWEEN 1995 AND 2003 IN MEXICO.

Location	Date	Pepper fruits	Parasitoid specimens	Pepper weevil emerged	Collector
Tapachula, Chiapas	Dec 24-30, 1995	100	10	20	Stansly
Tabasco	Apr 1, 1996	150	28	521	Stansly
Col. S. Marmol, Col. H. Pino S., and Jalpa de Méndez, Tabasco	May 28-29, 1997	1499	5	575	Stansly & Schuster
Col. H. Pino S., Tabasco	Sep 1997	501	2	108	Stansly
Yecapixtla, Morelos	Mar 1999	45	1	7	Rodríguez-Leyva
Santiago Suchiquiltongo, Oaxaca	Jun 1999	No data	360	Not indicated	Bravo
Puente Nacional, Veracruz	Apr 2000	180	20	98	Rodríguez-Leyva
Hato de la Higuera, Veracruz	Nov 2000	115	5	20	Rodríguez-Leyva
Santiago Ixcuintla, Nayarit	Apr 4-6, May 15-18, 2003	50 kg	139	4734	Rodríguez-Leyva
Abasolo, Cuilapan de Guerrero, Santiago Suchiquiltongo, San Juan Guelatilla, Oaxaca	Jul 2003	16 kg	48	434	Stansly
Total			618	6517	

of *Capsicum annuum* L. were collected, especially 'Serrano' but also 'Serranillo', 'Caloro', 'Jalapeño', 'Poblano', 'Chile de agua', 'Solterito' and 'Habanero' (*C. chinense*). Fruits were held in the laboratory in 3.8-L plastic containers provided with holes measuring 3 cm in diameter covered with organdy for ventilation. Some peppers were held at a room temperature of 25°C in the Colegio de Postgraduados, in Mexico, and others were received in the quarantine facilities at the Florida Department of Agriculture and Consumer Services, Division of Plant Industry, in Gainesville, Florida. There, peppers were held in the maximum security room at 25 to 28°C, 50 to 70% R.H. and 12:12 (L:D) photoperiod.

Approximately 90 kg of peppers infested by pepper weevil were sampled from both the Pacific and Atlantic Coasts in Mexico. The pepper fruits were not dissected, so it was not possible to be certain from which host stage the parasitoids emerged. Furthermore, there was always the possibility that parasitoids could emerge from different hosts, even though we included only pepper fruits with signs of pepper weevil damage. Such hosts could include Diptera that can develop in mined rotten fruit, the pepper flower-bud moth, *Symmetrischema capsica* (Bradley & Polovny) (Lepidoptera: Gelechiidae), which is known from Mexico (Bradley & Polovny 1965; Bennett 1995), or other parasitoids and hyperparasitoids. Therefore, the biology and hosts records of all collected parasitoid species were verified in the literature and the references cited in the text.

Percent of parasitism of *A. eugenii* was calculated by dividing the number of parasitoids by the total number of insects emerged (parasitoids plus weevils) and multiplying by 100 (Mariscal et al. 1998; Toapanta 2001).

All emerged parasitoids were preserved in 70% alcohol except for *T. eugenii* and *Urosigalphus* sp., which were used to establish a colony in quarantine in 2003. Preserved specimens were identified with the aid of available literature (Burks 1954; DiGiulio 1997; Gibson 1997; Quicke 1997; Schauff et al. 1997; Sharkey 1997; Wharton & López-Martínez 2000), and sent to specialists for verification. R. Wharton and R. Lomelí (Texas A&M University) verified Braconidae and parasitic Chalcidoidea, respectively, when the material was in the United States, and J. A. Sánchez from the Instituto Politécnico Nacional (IPN-CIDIR-Oaxaca-Mexico) verified braconids in Mexico. Voucher specimens are held at the Division of Plant Industry, Florida State Collection of Arthropods, Florida Department of Agriculture and Consumer Services, Gainesville, Florida; and the Entomology and Acarology Program at the Colegio de Postgraduados, Mexico.

RESULTS AND DISCUSSION

Weevils and parasitoids were present in each region, although abundance and diversity varied among locations and years (Table 1). A total of 618

parasitoids were recovered during our surveys along with an estimated 6,500 pepper weevil adults. Seven parasitoid species, which emerged from weevil-infested fruit, were collected by us and 6 more have been reported in the literature (Table 2). Parasitoids represented 3 genera of Braconidae, and 1 of Pteromalidae, Eulophidae, Eupelmidae, and Eurytomidae. Only *Ceratoneura* sp. (Eulophidae) was a new record for *A. eugenii*, although the host was not verified. Two species of Braconidae, *Triaspis eugenii* Wharton & López-Martínez and *Urosigalphus* sp., and the pteromalid *Catolaccus hunteri* Crawford represented 96% of all recovered parasitoids during our surveys. However, the relative proportion of each species varied among surveys, most notably with the dominance of *T. eugenii* reported from Nayarit (Mariscal et al. 1998; Toapanta 2001), and the large number of *Urosigalphus* sp. that were collected during our surveys in the state of Oaxaca (Table 2).

Braconidae: Helconinae: Brachistini

Triaspis eugenii. This species has only been reported from Nayarit (Fig. 1), where high levels of parasitism (18-40%) were reported (Mariscal et al. 1998; Toapanta 2001). These authors found that *T. eugenii* constituted 29% of 2,475 parasitoids, and 88.4% of 1,210 parasitoids, respectively. Nevertheless, 2 collections of infested fruit made at the same sites in 2003 yielded almost 5,000 pepper weevils, but only 9 *T. eugenii* (Rodríguez-Leyva 2006). A possible explanation for the paucity of *T. eugenii* in 2003 is the destruction of the pepper crops or alternate hosts and nectar sources by hurricane Kenna (October 24, 2002). Furthermore, the delayed season following replanting assured continued use of insecticides during the latter months of that season when collections were made.

Urosigalphus sp. According to Bravo (unpublished data) this undescribed species of wasp parasitized almost 30% of the population of the pepper weevil in experimental plots free of insecticides in Santiago Suchiquiltongo, Oaxaca. However, much fewer were collected from there and 3 others in the same region (Table 2, Fig. 1) during 2003, presumably due to the intense use of insecticides directed at the pepper weevil.

This genus also was reported on pepper weevil from Nayarit by Mariscal et al. (1998) and Toapanta (2001), although incidence in Nayarit was very low (5 specimens, Table 2). An *Urosigalphus* species attacking pepper weevil also was observed in Morelos (Table 2). Further taxonomic and ecological research will be required to understand the abundance of this genus in some places in Mexico.

Aliolus sp. Specimens were not recovered during our surveys, although Mariscal et al. (1998) collected 3 specimens of this genus which is the only reference relating it to the pepper weevil.

TABLE 2. PARASITIDS OF THE PEPPER WEEVIL RECORDED FROM MEXICO.

Parasitoid species	Location and date	Individuals collected	Reference
Braconidae			
<i>Triaspis eugenii</i> Wharton & López-Martínez	Santiago Ixcuintla, Nayarit, Jan to Apr 1997	729	Mariscal et al. (1998)
	Mar 1999	241	Toapanta (2001)
	May 1999	278 ♀, 188 ♂	Toapanta (2001)
	Mar and Apr 2000	198 ♀, 165 ♂	Toapanta (2001)
	Apr and May 2003	5 ♀, 4 ♂	Rodríguez-Leyva (2006)
<i>Urosigalphus</i> sp.	Santiago Ixcuintla, Nayarit, Jan to Apr 1977	4	Mariscal et al. (1998)
	Santiago Suchiuiltongo, Oaxaca, Jun 1999	360	Bravo (unpublished)
	Yecapixtla, Morelos, Mar 1999	1 ♀	Rodríguez-Leyva (unpublished)
	Santiago Ixcuintla, Nayarit	Not indicated	Toapanta (2001)
	Santiago Suchiuiltongo, Oaxaca, Jul 2003	14 ♀, 9 ♂	Stansly (unpublished)
	Juan José Ríos, Ahome, Sinaloa	1	Cortéz et al. (2002)
<i>Aliolus</i> sp.	Santiago Ixcuintla, Nayarit, January to Apr 1977	1 ♀, 2 ♂	Mariscal et al. (1998)
<i>Bracon mellitor</i> Say	Apodaca, Nuevo León	Not indicated	Barajas (1986)
<i>Bracon</i> sp.	Santiago Ixcuintla, Nayarit, Jan to Apr 1997	11	Mariscal et al. (1998)
	Santiago Ixcuintla, Nayarit	Not indicated	Toapanta (2001)
	Santiago Ixcuintla, Nayarit, Apr 2003	1 ♀, 1 ♂	Rodríguez-Leyva (2006)
	Cuilapan de Guerrero, Oaxaca, Jul 2003	1 ♀	Stansly (unpublished)
	Valle de Culiacán, Sinaloa, 2003	2	Pérez et al. (2003)
	Río Bravo, Tamaulipas, 2003	2	Rodríguez del Bosque & Reyes-Rosas (2003)
Pteromalidae			
<i>Catolaccus hunteri</i> Crawford	Tapachula, Chiapas, Dec 1995	10	Schuster and Stansly (unpublished)
	Jalpa Méndez, Tabasco, Apr 1996	28	Idem (unpublished)
	Tabasco, May and Sep 1997	5 ♀, 4 ♂	Idem (unpublished)
	Baja California Sur, Mar to Jul 1995	Not indicated	Aguilar & Servín (2000)
	Santiago Ixcuintla, Nayarit, Jan to Apr 1997	87	Mariscal et al. 1998
	Todos Santos, Baja California Sur, Jun 2000	5 ♀, 3 ♂	B. Calderón (unpublished)
	Puente Nacional, Veracruz; Apr 2000	12 ♀, 6 ♂	Rodríguez-Leyva (unpublished) Rodríguez-Leyva (2006)
	Hato de la Higuera, Veracruz; Nov 2000	2 ♀, 3 ♂	
	Santiago Ixcuintla, Nayarit, Apr and May 2003	88 ♀, 27 ♂	
	Santiago Ixcuintla, Nayarit, Mar-May 1999-2000	102	Toapanta (2001)
	Juan José Ríos, Ahome, Sinaloa	65	Cortéz et al. (2002)
	Santiago Suchiuiltongo, Oaxaca, Jul 2003	10 ♀, 5 ♂	Stansly (unpublished)
	Río Bravo, Tamaulipas, 2003	37	Rodríguez del Bosque & Reyes-Rosas (2003)
<i>Catolaccus</i> sp.	Apodaca, Nuevo León	Not indicated	Barajas (1986)
	Valle de Culiacán, Sinaloa	52	Pérez et al. (2003)
Eulophidae			
<i>Euderus</i> sp.	Santiago Ixcuintla, Nayarit, Jan to Apr 1997	2	Mariscal et al. (1998)
<i>Sympiesis</i> sp.	Santiago Ixcuintla, Nayarit, Jan to Apr 1997	7 ♀, 1 ♂	Mariscal et al. (1998)
<i>Ceratoneura</i> sp.	Cuilapan de Guerrero, Oaxaca; Jul 2003	7 ♀, 1 ♂	Stansly (unpublished)
Eupelmidae			
<i>Eupelma</i> sp.	Apodaca, Nuevo León	Not indicated	Barajas (1986)
<i>Eupelmus</i> sp.	Santiago Ixcuintla, Nayarit, Jan to Apr 1997	12	Mariscal et al. (1998)
	Santiago Ixcuintla, Nayarit	Not indicated	Toapanta (2001)
	Valle de Culiacán, Sinaloa	1	Pérez et al. (2003)

TABLE 2. (CONTINUED) PARASITOIDS OF THE PEPPER WEEVIL RECORDED FROM MEXICO.

Parasitoid species	Location and date	Individuals collected	Reference
	Santiago Ixcuintla, Nayarit, May 2003	6 ♀, 1 ♂	Rodríguez-Leyva (2006)
	Río Bravo, Tamaulipas, 2003	4	Rodríguez del Bosque & Reyes-Rosas (2003)
Eurytomidae			
<i>Eurytoma</i> sp.	Apodaca, Nuevo León	Not indicated	Barajas (1986)
	Santiago Ixcuintla, Nayarit, Jan to Apr 1997	4 ♀, 5 ♂	Mariscal et al. (1998)
	Santiago Ixcuintla, Nayarit, Apr and May 2003	5 ♀, 2 ♂	Rodríguez-Leyva 2006
	Puente Nacional, Veracruz, Apr 2000	1 ♀, 1 ♂	Rodríguez-Leyva (unpub)
	Valle de Cualiacán, Sinaloa, Jan to Jun 2003	18	Pérez et al. (2003)

The genus *Aliolus* has been reported as a primary parasitoid of Cerambycidae, Curculionidae, and Mordellidae (Martin 1956). *Aliolus* is represented in the United States and northern Mexico with possibly more than 30 species, although the most are undescribed (Martin 1956; Sharkey 1997). *Aliolus curculionis* (Fitch) and *A. rufus* (Riley) have been identified as primary parasitoids of the cotton boll weevil in the United States and Mexico and might parasitize other species (Cross & Chesnut 1971). More studies are needed to describe the biology of this genus, although low levels of parasitism indicate only incidental attack of pepper weevil.

Braconidae: Cheloninae

Chelonus sp. Although we did not collect specimens of this genus, it was collected by Toapanta (2001) in Nayarit, and by Pérez et al. (2003) in Sinaloa (Fig 1). This genus is included in the subfamily Cheloninae, a group that is characterized as being egg-larval endoparasitoids of Lepidoptera, especially microlepidoptera (Hentz et al. 1997; Shaw 1997). *Chelonus phtorimaeae* Gahan and *Chelonus* sp. have been collected from the pepper flower-bud moth, cited earlier. Consequently, it may have emerged from a host other than the pepper weevil in the previous reports and is not included in Table 2.

Braconidae: Braconinae

Bracon mellitor Say was long ago recorded as a parasitoid of the cotton boll weevil and the pepper weevil (Pratt 1907; Pierce et al. 1912). This generalist ectoparasitoid has more than 20 known hosts (Cross & Chesnut 1971). *Bracon mellitor* was the most abundant native parasitoid of the cotton boll weevil in the United States and possibly northern Mexico (Cross & Chesnut 1971), and also reported by Barajas (1986) on pepper weevil

from Nuevo León (Fig. 1). Because females search for hosts mainly on cotton plants and not on the ground, where the third instar host is often found in abscised floral buds, it is not considered to have potential in being an effective biological control agent of the boll weevil (Adams et al. 1969; Cate 1985; Cate et al. 1990). It may have the same limitations as a natural enemy of pepper weevil in that infested floral buds and immature fruits often abscise (Cano & Alcacio 1894; Walker 1905; Pratt 1907; Elmore et al. 1934).

Bracon sp. This genus was one of the least abundant parasitoids recovered from the pepper weevil, with only 2 specimens from Oaxaca and 1 from Nayarit. A few specimens of this genus were reported by Mariscal et al. (1998) and Toapanta (2001) from Nayarit, Pérez et al. (2003) from Sinaloa, and Rodríguez del Bosque & Reyes-Rosas (2003) from Tamaulipas (Fig. 1). We know that the 3 specimens collected from Oaxaca and Nayarit during 2003 are not *B. mellitor* Say (R. Lomelí 2005, personal communication), but comparisons with the other specimens were not possible.

Pteromalidae

Catolaccus hunteri was one of the first parasitoids reported from the pepper weevil (Pratt 1907; Pierce et al. 1912; Wilson 1986; Rodríguez-Leyva et al. 2000). It is a cosmopolitan and generalist ectoparasitoid of at least 17 species of Curculionidae and 2 of Bruchidae (Cross & Chesnut 1971). It also seems to be present throughout Mexico (Fig. 1), and represented 30% of the parasitoids collected.

Catolaccus hunteri has been collected from the Peruvian coast parasitizing the Peruvian cotton boll weevil, *Anthonomus vestitus* Boheman (Townsend 1912; Gahan 1951). In Central America it parasitizes the cotton boll weevil and the pepper weevil (Cross & Mitchell 1969; Cross & Chesnut 1971; Schuster & Stansly, unpublished data). In many places in Mexico it has been collected parasitizing

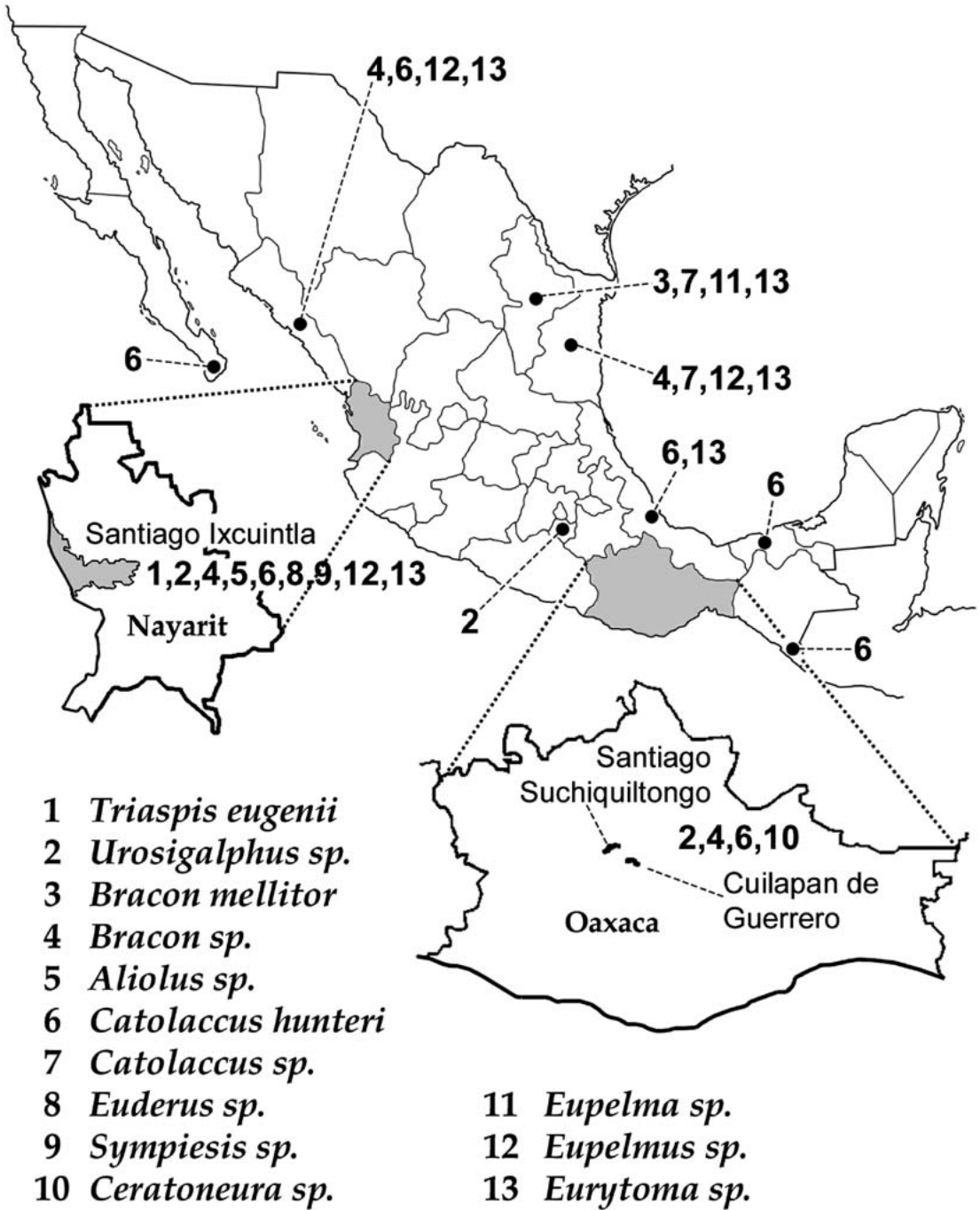


Fig. 1. Distribution of pepper weevil parasitoids reported from Mexico.

cotton boll weevil, pepper weevil, and *A. hunteri* (Cross & Mitchell 1969; Cross & Chesnut 1971; Cate et al. 1990; Bárcenas et al. 1997; Mariscal et al. 1998; Aguilar & Servín 2000; Toapanta 2001), and in the southern and eastern United States it parasitizes cotton boll weevil, pepper weevil (Cross

& Mitchell 1969; Wilson 1986; Schuster & Stansly, unpublished data) and *Anthonomus macromalus* Gyllenhal (Hunsberger & Peña 1997).

The wide host range of this species provided an opportunity to mass rear at a moderate scale on the cowpea weevil, *Callosobruchus maculatus* F.

(Coleoptera: Bruchidae), (Rodríguez-Leyva et al. 2002; Vazquez et al. 2005). Subsequent laboratory studies show that *C. hunteri* has greater fecundity and intrinsic rate of increase than pepper weevil (Rodríguez-Leyva et al. 2000; Seal et al. 2002), which stimulated and supported the plan of evaluating *C. hunteri* as a biological control agent of pepper weevil. However, releases of 1,050 *C. hunteri* per hectare in Sinaloa, Mexico, were not effective in combating pepper weevil on bell pepper (Corrales 2002). Nevertheless, augmentative releases of this parasitoid before crop establishment on the alternative host plant nightshade (equivalent of 7,900 *C. hunteri* / ha/ wk), which has small fruits, followed by releases on adjacent pepper reduced the number of weevil-damaged fruits (Schuster 2007). Releases early in the crop cycle when fruits are small, or in small fruit varieties, might be effective because the host is accessible to *C. hunteri*. Unfortunately, once the fruits increase in size, the ability of the parasitoid to attack pepper weevil is very limited. In fact, Riley and Schuster (1992) indicated that *C. hunteri* was not detected in fallen fruits larger than 2.5 cm in diameter.

Eulophidae

Euderus sp. *Sympiesis* sp. and *Ceratoneura* sp. are genera of Eulophidae recorded from pepper fruits infested by the pepper weevil (Table 2). *Euderus* species have been reported as primary parasitoids of Lepidoptera, Coleoptera, and even some Hymenoptera, especially Cynipidae (Schauff et al. 1997). *Sympiesis* species are indicated as parasitoids of leaf-mining Lepidoptera. *Ceratoneura* species are associated with galls, usually of Cecidomyiidae (Schauff et al. 1997), or as primary parasitoids of some Curculionidae (Lomelí, personal communication). It is remarkable that no species of the 3 genera have been reported as parasitoids of the cotton boll weevil (*A. grandis*) in spite of decades of search for natural enemies in the United States, Mexico, and Central America (Pierce et al. 1912; Cross & Mitchell 1969; Cross & Chesnut 1971). This is evidence that the relationship between these species and pepper weevil is still unclear.

Eupelmidae

Eupelmus sp. Seven specimens were recovered from Nayarit in 2003. This or a similar species was recovered in small numbers by Barajas (1986), Mariscal et al. (1998), and Pérez et al. (2003). *Eupelmus* is a large genus with many species distributed worldwide. They are reported as primary or secondary parasitoids of different holometabolous insects, usually concealed hosts protected by cocoons, galls, or other plant tissue (Gibson 1997). There is no information about its biology on the pepper weevil. *Eupelmus cushmani*

Crawford and *E. cyaniceps* Ashmead have been identified as primary parasitoids of cotton boll weevil; the first collected from Sonora in the north of Mexico and Guatemala (Clausen 1978), and the second from Morelos and Guerrero, in the south of Mexico (Cross & Chesnut 1971). It was introduced and released at the same time as *C. hunteri* in Hawaii during 1934-1937 in a classical biological program against pepper weevil. This natural enemy is established in Hawaii (Clausen 1978) but we do not have any information of its importance on the pepper weevil.

Eurytomidae

Eurytoma sp. We recovered 9 specimens from this genus, 2 from the Gulf Coast in Veracruz, and 7 from the Pacific Coast in Nayarit (Table 2). At least 3 different species were collected, although their identities remain undetermined (R. Lomelí, personal communication). A few specimens of this genus were collected by Mariscal et al. (1998) in Nayarit, Barajas (1986) in Nuevo León, and Pérez et al. (2003) in Sinaloa (Fig. 1). Species of the genus *Eurytoma* are known to be solitary ectoparasitoids of Coleoptera, Lepidoptera, Diptera, Hymenoptera and Homoptera (DiGiulio 1997). The species *E. gossypii* was identified as a primary parasitoid of the cotton boll weevil (Cross & Chesnut 1971), and an unknown species (*Eurytoma* sp.) was indicated as hyperparasitoid of *Zatropis* sp. in Morelos, Mexico (Pérez 1985). It is possible that the hyperparasitic habit and the low numbers recovered during different surveys make this an unlikely candidate for biological control of the pepper weevil.

T. eugenii and *Urosigalphus* sp.

as Biological Control Agents of Pepper Weevil

The genera *Triaspis* Haliday, and *Urosigalphus* Ashmead (Hymenoptera: Braconidae: Heliconinae: Brachistini) (Martin 1956; Sharkey 1997) are distributed worldwide, with nearly 100 known species each in the New World. However, only a few have been described from Mexico and Central America (Sharkey 1997).

The biology and life histories of most species are little known; many are egg-larval parasitoids of weevils, bruchids, and anthribids, with an ectoparasitic phase in the last instar (Clausen 1954; Shaw & Huddleston 1991; Berry 1947; Sharkey 1997). *Triaspis eugenii* from Nayarit, and *Urosigalphus* sp. from Oaxaca (Rodríguez-Leyva, unpublished data), are solitary parasitoids that attack the egg of their pepper weevil host, develop as endoparasitoids in early instars and emerge at the end of the last instar to feed as ectoparasitoids. The host is completely consumed, leaving only the cephalic capsule (Rodríguez-Leyva 2006).

Despite the fact that 11 parasitoid genera have been collected from the pepper weevil (Pratt 1907;

Pierce et al. 1912; Elmore et al. 1934; Cross & Chesnut 1971; Barajas 1986; Mariscal et al. 1998; Toapanta 2001; Rodríguez-Leyva 2006), only *T. eugenii* from Nayarit and *Urosigalphus* sp. from Oaxaca are known to parasitize the egg of this pest (Rodríguez-Leyva, unpublished data). The egg of the pepper weevil could be considered the stage more ecologically susceptible to be parasitized because it is deposited close to the surface of the pepper fruit, and therefore, is more accessible to parasitism than later stages located within the interior of the fruit. This is evident by the relatively high levels of parasitism of pepper weevil by *T. eugenii* (18-40%, Mariscal et al. 1998; Toapanta 2001) and *Urosigalphus* sp. (30%, E. Bravo, unpublished data) in the field. The potential for augmentative biological control may be much higher, based on laboratory results of 70-90% parasitism (Rodríguez-Leyva, unpublished data). Numerous records and high levels of parasitism suggest that these 2 species require further studies in order to (a) better understand their roles as natural enemies of the pepper weevil in their respective regions of Mexico, (b) further evaluate their potential as biological control agents of this pest, and (c) establish tactics for including them in IPM programs against the pepper weevil.

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REFERENCES CITED

- ABREU, E., AND C. CRUZ. 1985. Occurrence of pepper weevil *Anthonomus eugenii* Cano (Coleoptera: Curculionidae) in Puerto Rico. *J. Agri. Univ. Puerto Rico*. 59: 223-224.
- ADAMS, C. H., W. H. CROSS, AND H. C. MITCHELL. 1969. Biology of *Bracon mellitor*, a parasite of the boll weevil. *J. Econ. Entomol.* 62: 889-896.
- AGUILAR, R., AND R. SERVÍN. 2000. First record of *Catolaccus hunteri*, a parasitoid of *Anthonomus eugenii* Cano in Baja California Sur, Mexico. *Southwest. Entomol.* 25: 151-152.
- ANDREWS, K., A. RUEDA, G. GANDINI, S. EVANS, A. ARANGO, AND M. AVEDILLO. 1986. A supervised control program for the pepper weevil, *Anthonomus eugenii* Cano, in Honduras, Central America. *Trop. Pest. Manag.* 32: 1-4.
- ARCOS, G., J. HERNÁNDEZ, D. E. URIZA, O. POZO, AND A. OLIVERA. 1998. Tecnología para producir chile jalapeño en la planicie costera del Golfo de México. Instituto Nacional de Investigaciones Agrícolas, Secretaría de Agricultura Ganadería y Recursos Hidráulicos. Folleto Técnico 24. México.
- BARAJAS, R. 1986. Aspectos biológicos del picudo del chile (*Anthonomus eugenii* Cano) y evaluación de tres insecticidas para su combate en Apodaca, Nuevo León. Tesis de Lic. ITESM, Monterrey, Nuevo León. México.
- BÁRCENAS, N. M., G. GARCÍA, R. MERAZ, R. W. JONES, R. SOLÍS, AND E. G. KING. 1997. Establecimiento in situ de líneas de laboratorio de *Catolaccus grandis* Burks y *C. hunteri* Crawford (Hymenoptera: Pteromalidae) de la región del Soconusco, Chiapas, pp. 187-190 *In* G. M. Vázquez, M. T. Bernal, G. S. Rivera, and G. L. Borja. 1997 [eds.], Memorias del XX Congreso Nacional de Control Biológico, Guadalajara, Jal. México.
- BENNETT, F. D. 1995. Parasites of the pepper flower-bud moth (Lepidoptera: Gelechiidae) in Florida. *Florida Entomol.* 78: 546-549.
- BERRY, P. 1947. *Anthonomus vestitus* and its natural enemies in Peru, and their importation into the United States. *J. Econ. Entomol.* 40:801-804.
- BRADLEY, J. D., AND D. POLOVNY. 1965. The identity of the pepper flower-bud moth. *Bull. Entomol. Res.* 56: 57-65.
- BURKE, H. R., AND R. E. WOODRUFF. 1980. The Pepper Weevil (*Anthonomus eugenii* Cano) in Florida (Coleoptera: Curculionidae). Florida. Dept. Agr. Consumer Serv. Entomol. Cir. 219. 4 pp.
- BURKS, B. D. 1954. Parasitic Wasps of the *Catolaccus* Group in the Americas. USDA Tech. Bull. 1093: 1-20.
- CAMPBELL, R. E. 1924. Injuries to pepper in California by *Anthonomus eugenii* Cano. *J. Econ. Entomol.* 17: 645-647.
- CANO AND D. ALCACIO. 1894. El barrenillo. *La Naturaleza*. 2: 377-379.
- CATE, J. R. 1985. Cotton: status and current limitations to biological control in Texas and Arkansas, pp. 537-556 *In* M. A. Hoy and D. C. Herzog [eds.], Biological Control in Agricultural IPM systems. Academic Press, Inc., New York.
- CATE, J. R., P. C. KRAUTER, AND K. E. GODFREY. 1990. Pest of cotton, pp. 17-29 *In* D. H. Habeck, F. D. Bennett, and J. H. Frank [eds.], Classical Biological Control in the Southern United States. South. Coop. Ser. Bull. 355.
- CLAUSEN, C. P. 1954. Entomophagous Insects. Reinhold Publ. Corp.
- CLAUSEN, C. P. 1978. Curculionidae, pp. 259-276 *In* C. P. Clausen [ed.], Introduced Parasites and Predators of Arthropod Pests and Weeds. A World Review. USDA. Agriculture Handbook 480.
- CORRALES, M. J. L. 2002. Estrategias Bioracionales para el Manejo de las Principales Plagas del Cultivo del Chile en la Cruz de Elota, Sinaloa. Tesis de Doctorado, Colegio de Postgraduados, Montecillo, Tlaxcala, México. 113 pp.
- CORTÉZ, M. E., E. CABANILLAS, AND J. A. SÁNCHEZ. 2002. Búsqueda de parasitoides del picudo del chile,

- Anthonomus eugenii* Cano (Coleoptera: Curculionidae), en el norte de Sinaloa, pp. 96-98, *In* R. Báez and J. J. Juvera [eds.], XXV Congreso Nacional de Control Biológico, SMCB A. C., Hermosillo, Sonora, México.
- COTO, D. 1996. El Picudo del Chile (*Anthonomus eugenii* Cano) su Reconocimiento y Posible Manejo. Manejo Integrado de Plagas (Costa Rica), hoja técnica 19. 4 pp.
- CROSS, W. H., AND T. L. CHESNUT. 1971. Arthropod parasites of the boll weevil, *Anthonomus grandis*: 1. An annotated list. *Ann. Entomol. Soc. Am.* 64: 516-527.
- CROSS, W. H., AND H. C. MITCHELL. 1969. Distribution and importance of *Heterolaccus grandis* as parasite of the boll weevil. *Ann. Entomol. Soc. Am.* 62: 235-236.
- DIGIULIO, J. A. 1997. Eurytomidae, pp. 477-495 *In* G. A. P. Gibson, J. T. Huber, and J. B. Woolley [eds.], Annotated Keys to the Genera of Nearctic Chalcidoidea (Hymenoptera). National Research Council of Canada Monograph Publishing Program, Ontario, Canada.
- ELMORE, J. C., A. C. DAVIS, AND R. F. CAMPBELL. 1934. The Pepper Weevil. USDA. Tech. Bull. 447. 27 p.
- ELMORE, J. C., AND R. E. CAMPBELL. 1954. Control of the pepper weevil. *J. Econ. Entomol.* 47: 1141-1143.
- ESHBAUGH, W. H. 1976. Genetic and biochemical systematic studies of chili peppers (*Capsicum-Solanaceae*). *Bull. Torrey Bot. Club* 102: 396-403.
- GAHAN, A. B. 1951. Some synonymy and new combination in Chalcidoidea (Hymenoptera). *Can. Entomol.* 83: 170-176.
- GENUNG, W. G., AND H. Y. OZAKI. 1972. Pepper Weevil on the Florida East Coast. Belle Glade mimeo report. University of Florida. 15 pp.
- GIBSON, G. A. P. 1997. Eupelmidae, pp. 430-476 *In* G. A. P. Gibson, J. T. Huber, and J. B. Woolley [eds.], Annotated Keys to the Genera of Nearctic Chalcidoidea (Hymenoptera). National Research Council of Canada Monograph Publishing Program, Ontario.
- GOFF, C. C., AND J. W. WILSON. 1937. The pepper weevil. University of Florida, Agric. Exp. Sta. Bull. 310: 3-11.
- HENTZ, M., P. ELLSWORTH, AND S. NARANJO. 1997. Biology and morphology of *Chelonus* sp. nr. *curvimaculatus* (Hymenoptera: Braconidae) as a parasitoid of *Pectinophora gossypiella* (Lepidoptera: Gelechiidae). *Ann. Entomol. Soc. Am.* 90: 631-639.
- HUNSBERGER, A. G., AND J. E. PEÑA. 1997. *Catolaccus hunteri* (Hymenoptera: Pteromalidae), a parasite of *Anthonomus macromalus* (Coleoptera: Curculionidae) in South Florida. *Florida Entomol.* 80: 301-304.
- LOAIZA-FIGUEROA, F., K. RITLAND, J. CANCINO, AND S. D. TANKSLEY. 1989. Patterns of genetic variation of the genus *Capsicum* (Solanaceae) in Mexico. *Plant Syst. Evol.* 165: 159-188.
- MACNEISH, R. S. 1964. Ancient Mesoamerican civilization. *Science* 143: 531-537.
- MARISCAL, M. E., J. L. LEYVA, AND R. BUJANOS. 1998. Parasitoides del picudo del Chile, *Anthonomus eugenii* Cano (Coleoptera: Curculionidae), en Nayarit, México. *Vedalia* 5: 39-46.
- MARTIN, J. C. 1956. A Taxonomic Revision of the Triaspidinae Braconid Wasps of Nearctic America (Hymenoptera). Canadian Department of Agriculture, Pub. 965.
- PATROCK, R. J., AND D. J. SCHUSTER. 1992. Feeding, oviposition, and development of the pepper weevil (*Anthonomus eugenii* Cano) on selected species of Solanaceae. *Trop. Pest Manag.* 38: 65-69.
- PÉREZ, L. G. 1985. Himenópteros parasitoides de *Apion* spp. (Coleoptera: Curculionidae: Apionidae) en Tepoztlán, Morelos. *Folia Entomol. Mexicana* 63: 39-46.
- PÉREZ, P., H. GONZÁLEZ, A. GONZÁLEZ, J. L. CORRALES, AND E. CORTÉZ. 2003. Búsqueda de parasitoides de *Anthonomus eugenii* Cano (Coleoptera: Curculionidae) en el centro de Sinaloa, pp. 152 *In* XIV Congreso nacional de investigación y desarrollo tecnológico agropecuario (SEP/SEIT/DGETA), El Salto, Pueblo Nuevo, Durango, México.
- PICKERSGILL, B., AND C. B. HEISER, JR. 1971. Origins and distribution of plants domesticated in the New World tropics, pp. 803-835 *In* C. A. Reed [ed.], *Origins of Agriculture*. Mouton Publisher The Hague, Paris.
- PIERCE, W. D., R. A. CUSHMAN, AND C. E. HOOD. 1912. The insect enemies of the cotton boll weevil. *USDA Bur. Entomol. Bul.* 100: 1-99.
- PRATT, F. C. 1907. Notes on the pepper weevil. *USDA Bur. Entomol. Bul.* 63: 55-58.
- QUICKE, D. L. J. 1997. Subfamily Braconidae, pp. 149-174 *In* R. Wharton, P. M. Marsh, and M. Sharkey [eds.], *Manual of the New World Genera of the Family Braconidae* (Hymenoptera). Special Publication No. 1. International Society of Hymenopterists. Washington D.C.
- RILEY, D. G., AND E. G. KING. 1994. Biology and management of pepper weevil *Anthonomus eugenii* Cano (Coleoptera: Curculionidae): a review. *Trends Agri. Sci.* 2: 109-121.
- RILEY, D. G., AND D. J. SCHUSTER. 1992. The occurrence of *Catolaccus hunteri*, a parasitoid of *Anthonomus eugenii*, in insecticide treated bell pepper. *Southwest. Entomol.* 17: 71-72.
- RILEY, D. G., AND A. N. SPARKS, JR. 1995. The Pepper Weevil and its Management. Texas Agricultural Extension Service, Texas A&M University. College Station. L-5069.
- RODRÍGUEZ-DEL-BOSQUE, L. A., AND M. A. REYES-ROSAS. 2003. Damage, survival, and parasitism of *Anthonomus eugenii* Cano (Coleoptera: Curculionidae) on piquin pepper in northern Mexico. *Southwest. Entomol.* 28: 293-294.
- RODRÍGUEZ-LEYVA, E. 2006. Life History of *Triaspis eugenii* Wharton and López-Martínez (Hymenoptera: Braconidae) and Evaluation of its Potential for Biological Control of Pepper Weevil *Anthonomus eugenii* Cano (Coleoptera: Curculionidae). Ph.D. Dissertation, University of Florida, Gainesville. 110 pp.
- RODRÍGUEZ-LEYVA, E., J. L. LEYVA, V. GÓMEZ, N. M. BÁRCENAS, AND G. W. ELZEN. 2000. Biology of *Catolaccus hunteri* (Hymenoptera: Pteromalidae), a parasitoid of pepper weevil and boll weevil (Coleoptera: Curculionidae). *Ann. Entomol. Soc. Am.* 93: 862-868.
- RODRÍGUEZ-LEYVA, E., V. GÓMEZ, N. M. BÁRCENAS, AND J. L. LEYVA. 2002. Efecto de diferentes factores sobre la cría de *Callosobruchus maculatus* (Coleoptera: Bruchidae) para la producción de *Catolaccus* spp. (Hymenoptera: Pteromalidae). *Acta Zool. Mexicana* (n.s.) 86: 87-101.
- SCHAUFF, M. E., J. LASALLE, AND L. D. COOTE. 1997. Eulophidae, pp. 327-429 *In* G. A. P. Gibson, J. T. Huber, and J. B. Woolley [eds.], *Annotated Keys to the Genera of Nearctic Chalcidoidea* (Hymenoptera). National Research Council of Canada Monograph Publishing Program, Ontario.
- SCHUSTER, D. J. 2007. Suppression of *Anthonomus eugenii* (Coleoptera: Curculionidae) pepper fruit infestation with releases of *Catolaccus hunteri* (Hymenoptera: Pteromalidae). *Biocontrol Sci. and Technol.* 17: 345-351

- SEAL, D. R., P. A. STANSLY, AND D. J. SCHUSTER. 2002. Influence of temperature and host on life history parameters of *Catolaccus hunteri* (Hymenoptera: Pteromalidae). *Environ. Entomol.* 31: 354-360.
- SHARKEY, M. J. 1997. Subfamily Helconinae, pp. 260-272 *In* R. Wharton, P. M. Marsh, and M. Sharkey [eds.], *Manual of the New World Genera of the Family Braconidae* (Hymenoptera). Special Publication No. 1. International Society of Hymenopterists. Washington, D.C.
- SHAW, S. R. 1997. Subfamily Cheloninae, pp.197-206 *In* R. A. Wharton, P. M. Marsh, and M. Sharkey [eds.], *Manual of the New World Genera of the Family Braconidae* (Hymenoptera). Special Publication No. 1. International Society of Hymenopterists. Washington, D.C.
- SHAW, M. R., AND T. HUDDLESTON. 1991. Classification and Biology of Braconid Wasps. *Handbooks for the Identification of British Insects.* 7: 1-126
- TOAPANTA, M. A. 2001. Population Ecology, Life History, and Biological Control of the Pepper Weevil, *Anthonomus eugenii* Cano (Coleoptera: Curculionidae). Ph. D. Dissertation, University of Florida, Gainesville, FL. 151 pp.
- TOWNSEND, C. H. 1912. The cotton square weevil of Peru and its parasites. *J. Econ. Entomol.* 5: 252-258.
- VAVILOV, N. I. 1951. *Phytogeographic Basis of Plant Breeding: the Origin, Variation, Immunity and Breeding of Cultivated Plants.* Translated by K. S. Chester. Chronica Botanica Co. 3. Liden Waltham, MA.
- VAZQUEZ, E., D. DEAN, D. J. SCHUSTER, AND P. V. ETTEN. 2005. A laboratory method for rearing *Catolaccus hunteri* (Hymenoptera: Pteromalidae), a parasitoid of the pepper weevil (Coleoptera: Curculionidae). *Florida Entomol.* 88: 191-194.
- VELASCO, P. H. 1969. Evaluación de pérdidas y preferencia de oviposición del picudo o barrenillo del Chile (*Anthonomus eugenii* Cano). Efectividad de varios insecticidas y reacción de diferentes variedades a su ataque. *Agricultura Técnica en México.* 26: 499-507.
- WALKER, C. M. 1905. The pepper weevil (*Anthonomus aeneotinctus* Champ). *USDA. Bur. Entomol. Bull.* 54: 43-48.
- WHARTON, R. A., AND V. LÓPEZ-MARTÍNEZ. 2000. A new species of *Triaspis* Haliday (Hymenoptera: Braconidae) parasitic of the pepper weevil *Anthonomus eugenii* Cano (Coleoptera: Curculionidae). *Proc. Entomol. Soc. Wash.* 102: 794-801.
- WILSON, R. J. 1986. Observations on the Behavior and Host Relations of the Pepper Weevil *Anthonomus eugenii* Cano (Coleoptera: Curculionidae) in Florida. M.S. Thesis, University of Florida, Gainesville.