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Parasitoids attacking fall armyworm (Lepidoptera: Noctuidae) in sweet corn habitats

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HIGHLIGHTS

- We collected over 8000 *Spodoptera frugiperda* larvae from sweet corn habitats during a 5-year period.
- *Cotesia marginiventris* and *Chelonus insularis* were the two most common parasitoids attacking fall armyworm larvae.
- Parasitism due to all species was higher in unsprayed fields than in fields potentially sprayed with insecticides.

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ABSTRACT

Fall armyworm larvae, *Spodoptera frugiperda* (J. E. Smith), were collected from sweet corn plants (*Zea mays* L.) in fields located in three south Florida counties. Fields were sampled from 2010 to 2015 during the fall and spring seasons. Larvae were transferred to the laboratory to complete development. The objective of the study was to identify the common parasitoids emerging from larvae that are present in sweet corn habitats where insecticides are traditionally used. A total of 8353 fall armyworm larvae were collected, of which 60.6% (5062) developed into moths after feeding on corn tissue and artificial diet. Parasitoids emerged from 2365 larvae (28.3%), and parasitism ranged from 1% to 91.7%, depending on site. Parasitism was higher at the University of Florida Everglades Research and Education (EREC) in Belle Glade (50.4 ± 11.8%) than at other locations in south Florida. Parasitism was comparable between fall and spring seasons, but was much higher in unsprayed fields (44.0 ± 9.6%) than in the sprayed fields (15.0 ± 2.5%). The two most common parasitoids that emerged from larvae were the solitary endoparasitoids *Cotesia marginiventris* (Cresson), found in 23 of the 25 sites sampled, and *Chelonus insularis* Cresson, found in 18 of the 25 sites sampled. Other parasitoid species that emerged from fall armyworm larvae were *Aleiodes laphygmae* (Viereck), *Euplectrus platyhypenae* Howard, *Meteorus* spp., *Ophion flavidus* Brullé, and unidentified species of Tachinidae. Techniques to improve the management of fall armyworm in overwintering areas of south Florida using conservation biological control are discussed.

1. Introduction

Florida leads the country in fresh market sweet corn production, harvesting almost 20% of the nation's total in 2013 (over 17,000 ha) for a value of $165.6 million (Anon., 2014a, 2014b). Over half of this production is in the south Florida counties of Palm Beach, Miami-Dade, and Hendry, where planting occurs from October to March (Mossler, 2008). Sweet corn is plagued by several direct insect pests that are managed by as many as 20 insecticide applications per season of 32 labeled compounds (Ozores-Hampton et al., 2014). These applications are sprayed during both the vegetative and reproductive stages of plants and include a variety of different modes of action.

One of the most serious pests of Florida sweet corn is the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Nuessly et al., 2007). This migratory noctuid attacks corn plants throughout their growth, infesting both sweet and field corn throughout the southeast, central, and eastern U.S. (Sparks, 1979; Pair et al., 1986b). In whorl-stage plants, young larvae feed on the outer leaves and move into the whorl, subsequently damaging the emerging tassels. All larval stages can feed on the ear, with young larvae feeding on the silks and entering through the cob tip; older larvae generally enter through the husk (Nuessly and Webb, 2001).

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Surveys have documented large numbers of parasitoid species emerging from fall armyworm larvae in the U.S. (Ashley, 1979; Pair et al., 1986a), Mexico (Molina-Ochoa et al., 2001, 2004), Central America and the Caribbean (Andrews, 1980, 1988; Wheeler et al., 1989), and South America (Bastos-Dequech et al., 2004; Murúa et al., 2006, 2009). In south Florida, three main species were collected including the egg-larval endoparasitoid *Chelonus insularis* Cresson (Braconidae, Cheloninae), and the larval endoparasitoids *Cotesia marginiventris* (Cresson) (Braconidae, Microgastrinae), and *Temelucha difficilis* Dasch (Ichneumonidae, Cremastinae) (Ashley et al., 1982, 1983; Pair et al., 1986a). However, these collections were made either in corn plots planted specifically for the study or in volunteer corn fields and were, therefore, most likely unsprayed by chemical or biological insecticides.

A percentage of the fall armyworm populations feeding in south Florida migrate northward each season (Pair et al., 1986b; Mitchell et al., 1991). Previous research suggested that high populations of potentially migrant fall armyworms occur in agricultural habitats located in the southern counties (Meagher and Nagoshi, 2004; Nagoshi and Meagher, 2004), and sweet corn production is one of the important crops in these areas. One area wide management practice that has potential to lower migratory populations is to promote biological control by increasing the floral complexity of these agricultural habitats (Tscharntke et al., 2007; Hinds and Hooks, 2013). The survival and reproduction of natural enemies requires provisioning of pollen and nectar sources in the landscape (Isaacs et al., 2009). Individual natural enemy species may have different responses to plant diversity and to the plant species inventory in these newly improved habitats (Shackelford et al., 2013; Tillman and Carpenter, 2014). Therefore, before prospective floral species are introduced, the important natural enemies must be identified and their impact quantified. The objectives of this work were to determine the species and abundance of common parasitoids emerging from larvae that are present in sweet corn habitats where insecticides are traditionally used, as well as habitats with little to no insecticide use.

2. Materials and methods

2.1. Field sites

The vegetative stage of the plants sampled was from V3 (third leaf) to just before VT (tasseling) (Abendroth et al., 2011). All of the Hendry Co. collections were from a vegetable farm (sweet corn and beans) along Co. Rd. 832 (N26°35′42″, W81°16′30″). The Miami-Dade Co. samples were from commercial sweet corn fields either in Florida City (N25°28′12″, W80°24′18″) or west of Kendall (N25°38′42″, W80°27′54″). The Palm Beach Co. sites were more dispersed, depending on the year because of the availability of grower fields. Samples were collected from unsprayed fields at the University of Florida Everglades Research and Education Center in Belle Glade (PB-EREC) (N26°40′7″, W80°38′6″) or in commercial sweet corn plantings north and east of PB-EREC. All sweet corn plants sampled were not genetically modified. Larvae were collected during the "fall" (November and December) or "spring" (February–April) sweet corn seasons, 2010–2015.

2.2. Collection of larvae

In the field, feeding injury in the leaf whorl and the presence of frass were used to direct the search for larvae. Larvae were pulled from the whorl and placed individually in 29.6 ml diet cups (Jet Plastica Industries, Hatfield, PA) with cut pieces of corn. An attempt was made at each site to collect at least 300 larvae, however larger numbers of larvae were collected in some fields. Cups were put in trays and placed in coolers. After returning from the field, larvae were identified and categorized based on size. Greenhouse-grown corn ('Truckers Favorite') was added to cups that contained young larvae until they reached about 4th instar; older larvae were placed in cups with artificial diet (Guy et al., 1985). Young larvae were initially placed on corn tissue because parasitoid mortality was higher when they were placed directly onto artificial diet. Once the young larvae reached 4th instar, they were then placed on artificial diet. Live larvae either developed into adults, produced adult parasitoids, died during development, or died as a result of handling (dried artificial diet or escaped). Larvae were held in incubators or large rearing units at ≈23 °C, 70% RH, and 14:10 h photoperiod. Parasitoids that emerged were preserved in 70% ethanol and sent for identification to the USDA-ARS Systematic Entomology Laboratory in Beltsville, MD. Parasitoid voucher specimens were placed in care of the author at the USDA-ARS CMAVE Insect Collection, Gainesville.

2.3. Data analysis

Percent live adults, dead larvae, and parasitism (number of parasitoids/number of larvae collected × 100) were compared across locations (Hendry, Miami-Dade, Palm Beach, and PB-EREC) and between the fall and spring seasons using Analysis of Variance without transformation (PROC Mixed, LS means; SAS 9.4, SAS Institute, 2012). Regression analysis of *Ch. insularis* percent parasitism vs. *C. marginiventris* percent parasitism was also conducted using SAS 9.4 (PROC REG).

3. Results

3.1. Larval collection

Fall armyworm larvae were collected from 25 field sites containing whorl-stage sweet corn plants that were located in commercial (17), experimental (intentionally planted) (6), or volunteer (plants result of non-harvested kernels) (2) fields and that did not contain genetically-modified corn varieties (Table 1). All commercial sweet corn fields were potentially sprayed with registered insecticides using the action threshold of 5–10% infestation. However, these fields were not sampled within 48 h of insecticide applications. The experimental and volunteer fields were unsprayed.

The 25 sites yielded 8353 fall armyworm larvae, 60.6 ± 4.3% of which developed into moths (50.3% male) after feeding on corn tissue and artificial diet (Table 1). Fewer larvae collected from PB-EREC developed into adults (39.0 ± 11.1%) than larvae collected from the other locations (Miami-Dade 60.8 ± 4.0%, Hendry 72.1 ± 5.4%, or Palm Beach 73.0 ± 8.4%; $F = 4.5$, d.f. = 3, 20, $P = 0.0139$). Adult moth emergence rate was similar for larvae collected during fall and spring seasons (61.9 ± 6.7% vs. 59.5 ± 5.6%, respectively; $F = 0.07$, d.f. = 1, 22, $P = 0.7874$). However more adults emerged from larvae collected in sprayed fields (67.6 ± 3.6%) than in unsprayed fields (45.9 ± 9.3%; $F = 6.9$, d.f. = 1, 22, $P = 0.0151$). Over 15% of the larvae died due to pathogens, handling, or escaping from the diet trays, and there was no difference in mortality among larvae collected from the sites (Miami-Dade 17.7 ± 6.3%, Hendry 16.6 ± 3.6%, Palm Beach 12.9 ± 4.1%, PB-EREC 10.6 ± 2.0%; $F = 0.4$, d.f. = 3, 20, $P = 0.7618$), seasons (fall 15.6 ± 2.8% vs. spring 14.6 ± 3.9%; $F = 0.09$, d.f. = 1, 22, $P = 0.7716$), or in sprayed or unsprayed fields (sprayed 17.4 ± 3.3% vs. unsprayed 10.1 ± 1.5%; $F = 2.3$, d.f. = 1, 22, $P = 0.1451$).

Over 48% of the larvae collected were "small", comprising 1st or 2nd instars, 22.7% were "medium" (3rd or 4th instars), and 29%

Table 1
Number of larvae (percent of total) collected from 2010 to 2015 in Hendry Co., Miami-Dade Co. (MB), Palm Beach Co. (PB), and Palm Beach-EREC (PB-EREC) during April (Apr), December (Dec), February (Feb), March (Mar), or November (Nov). All collections were from sweet corn fields of different varieties that were not genetically engineered. After development, the fate of each larva was noted: live, dead, or parasitized by *Cotesia marginiventris* (Cresson), *Chelonus insularis* Cresson, or another parasitoid.

Year	Location	Field type[a]	Month	No. larvae	Live male	Live female	Dead[b]	Parasitoids[c]
2010	Hendry	C	Nov	173	62	48	51	12
	MD	C	Nov	319	78	87	33	121
	PB	C	Dec	482	144	141	95	102
2011	Hendry	C	Mar	122	42	47	13	20
	MD	C	Feb	465	132	149	43	141
	MD	V	May[d]	384	251[e]		35	98
	PB	C	Feb	235	113	94	13	15
	Hendry	C	Nov	326	133	125	44	24
	MD	C	Nov	387	135	116	32	104
	PB	C	Nov	228	79	85	31	33
2012	Hendry	C	Mar	269	86	126	30	27
	MD	V	Feb[f]	273	102	84	21	66
	PB-EREC	E	Apr	333	37	34	29	233
	Hendry	C	Dec	550	109	125	169	147
	MD	C	Dec	378	110	102	111	55
2013	Hendry	C	Mar	319	136	116	29	38
	MD	C	Mar	294	63	58	170	3
	PB-EREC	E	Apr	267	74	78	26	89
	Hendry	C	Nov	223	103	107	8	5
	MD	C	Nov	314	121	126	30	37
	PB-EREC	E	Dec	456	6	8	24	418
2014	Hendry	C	Apr	300	105	94	73	28
	PB-EREC	E	Apr	478	65	56	91	266
	PB-EREC	E	Dec	148	59	56	20	13
2015	PB-EREC	E	Apr	630	313[e]		47	270

[a] C = commercial, E = experimental (intentionally planted), V = volunteer (plants result of non-harvested kernels).
[b] Death due to pathogens or handling, or larva escaped.
[c] Includes *Cotesia marginiventris* (Cresson), *Chelonus insularis* Cresson, *Aleiodes laphygmae* (Viereck), *Euplectrus platyhypenae* Howard, *Meteorus* spp., *Ophion flavidus* Brullé, Tachinidae, or unidentified.
[d] Collected in field of volunteer sweet corn.
[e] Gender not determined; numbers included in percentage of adults produced.
[f] Collected from unsprayed and abandoned sweet corn field.

were "large" (5th instar and above). This range of larval ages gave us an opportunity to collect parasitoids that attack different-sized larvae.

Parasitoids emerged from 2365 larvae (28.3%), and parasitism (number of parasitoids divided by the number of larvae collected × 100) ranged from 1% (Miami-Dade, March 2013) to 91.7% (PB-EREC, December 2013) (Table 1). Total parasitism (= parasitism due to all species) was over twice as high at PB-EREC (50.4 ± 11.8%) than Miami-Dade (21.5 ± 4.1%), Palm Beach (14.0 ± 4.3%) or Hendry (11.4 ± 2.6%) (F = 8.2, d.f. = 3, 20, P = 0.0009). Total parasitism was higher in the unsprayed fields (44.0 ± 9.6%) than in the sprayed fields (15.0 ± 2.5%) (F = 16.9, d.f. = 1, 22, P = 0.0005). Total parasitism was comparable between fall and spring seasons (22.6 ± 7.0% vs. 25.9 ± 5.7%, respectively; F = 0.23, d.f. = 1, 22, P = 0.6359).

3.2. Cotesia and Chelonus

The two most common parasitoids that emerged from fall armyworm larvae were *C. marginiventris* (1119/2365 = 47.3% of all parasitoids collected) and *Ch. insularis* (1102/2365 = 46.6%). Although *C. marginiventris* was found in 23 and *Ch. insularis* was collected in 18 of the 25 sites sampled, the distribution of these two species was different among sites (Fig. 1). Percent parasitism attributed to *C. marginiventris* (number of *C. marginiventris* wasps divided by number of larvae collected × 100) was similar among sites (Miami-Dade 16.9 ± 4.9%, Palm Beach 11.9 ± 3.6%, PB-EREC 10.7 ± 4.3%, Hendry 9.0 ± 2.9%; F = 0.9, d.f. = 3, 20, P = 0.4820). However, parasitism by *Ch. insularis* was much higher at PB-EREC

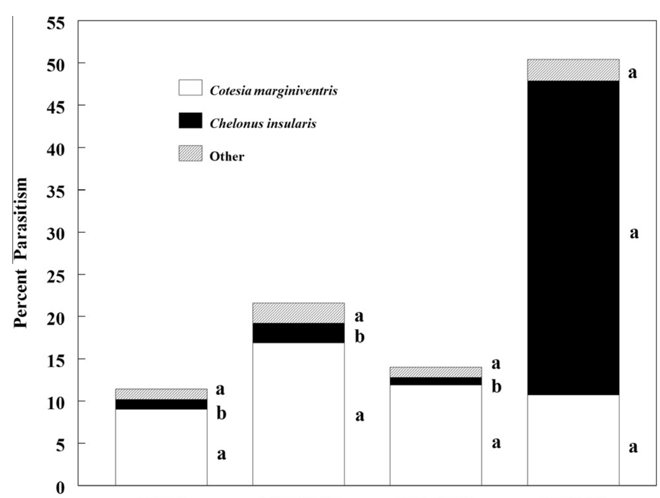

Fig. 1. Percent parasitism of fall armyworm larvae collected from sweet corn habitats in Hendry, Miami-Dade, and Palm Beach (PB) counties and at the Everglades Research and Education Center (PB-EREC) in Belle Glade, FL, 2010–2015, by *Cotesia marginiventris*, *Chelonus insularis*, or other parasitoids. Percent parasitism calculated as number of *C. marginiventris*, *Ch. insularis*, or other parasitoids divided by total number of larvae × 100, collected for individual sites. Means for *C. marginiventris*, *Ch. insularis*, or other parasitoids followed by the same letter are not significantly different, P > 0.05.

(37.2 ± 13.9%) than the other locations (Miami-Dade 2.3 ± 1.7%, Hendry 1.2 ± 0.8%, and Palm Beach 0.9 ± 0.7%; F = 6.7, d.f. = 3, 20, P = 0.0025; Fig. 1).

Cotesia marginiventris parasitism was similar in sprayed and unsprayed fields (13.2 ± 2.7% vs. 10.3 ± 3.5%, respectively; $F = 0.4$, d.f. = 1, 22, $P = 0.5213$; Fig. 2). However, parasitism due to *Ch. insularis* was dramatically higher in unsprayed fields (30.0 ± 11.3%) than in sprayed fields (0.8 ± 0.4%; $F = 15.0$, d.f. = 1, 22, $P = 0.0008$; Fig. 2). In fact, sites and fields that had high levels of parasitism by *C. marginiventris* appeared to have low levels of parasitism by *Ch. insularis*, resulting in a significant negative regression between these species (percent parasitism calculated as number of *C. marginiventris* or *Ch. insularis* divided by total number of parasitoids × 100 that emerged for individual sites) (Fig. 3).

We looked at the distribution of parasitism by *C. marginiventris* and *Ch. insularis* during the fall and spring collection seasons (Fig. 4). For *C. marginiventris*, parasitism was similar between both seasons (fall 13.0 ± 3.4% vs. spring 11.6 ± 2.7%; $F = 0.09$, d.f. = 1, 22, $P = 0.7626$). *Chelonus insularis* parasitism was also similar between seasons (fall 8.1 ± 7.5% vs. spring 12.0 ± 5.2%; $F = 0.18$, d.f. = 1, 22, $P = 0.6736$). The December 2013 collection at PB-EREC had a surprisingly high level of parasitization. When the results from that site were removed the analysis, there was a trend for parasitism by *Ch. insularis* to be higher in the spring than the fall collections (spring 12.0 ± 5.2% vs. fall 0.7 ± 0.3%; $F = 3.6$, d.f. = 1, 21, $P = 0.0743$).

3.3. Other parasitoids collected

Other parasitoid species that emerged from larvae were the solitary endoparasitoids *Aleiodes laphygmae* (Viereck) (47 individuals collected, 2.0% of all parasitoids collected), *Meteorus* spp. (9, 0.4%), *Ophion flavidus* Brullé (32, 1.4%), the gregarious ectoparasitoid *Euplectrus platyhypenae* Howard (19, 0.8%), and unidentified species of Tachinidae (37, 1.6%). Seven parasitoid larvae emerged from fall armyworm larvae but did not complete development and were not identified. Taken as a group, parasitism by the other parasitoids was not different among sites sampled (PB-EREC 2.5 ± 1.0%, Miami-Dade 2.4 ± 1.3%, Palm Beach 1.2 ± 0.3%, Hendry 1.2 ± 0.4%; $F = 0.5$, d.f. = 3, 20, $P = 0.6725$) (Fig. 1) or between seasons (fall 1.4 ± 0.5% vs. spring 2.3 ± 0.8%; $F = 0.94$, d.f. = 1, 22, $P = 0.3418$) (Fig. 4). However higher parasitism due to the other species was found in unsprayed fields than in sprayed fields (Fig. 2) (unsprayed 3.8 ± 1.2% vs. sprayed 1.0 ± 0.2%; $F = 10.0$, d.f. = 1, 22, $P = 0.0045$).

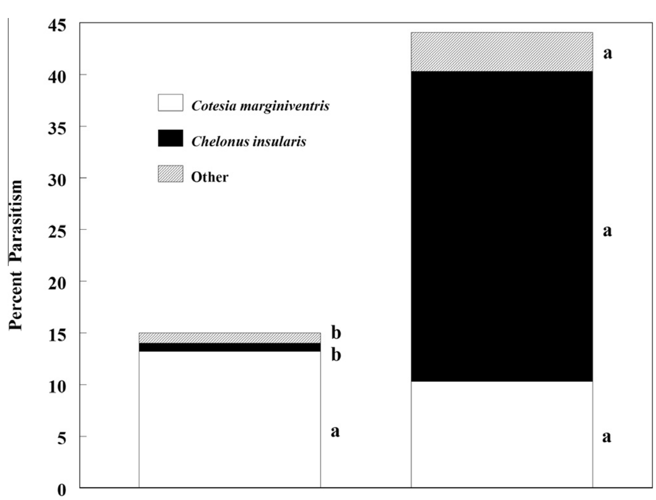

Fig. 2. Percent parasitism of fall armyworm larvae collected from unsprayed or potentially sprayed sweet corn habitats in Hendry, Miami-Dade, and Palm Beach (PB) counties and at the Everglades Research and Education Center (PB-EREC) in Belle Glade, FL, 2010–2015, by *Cotesia marginiventris*, *Chelonus insularis*, or other parasitoids. Percent parasitism calculated as number of *C. marginiventris*, *Ch. insularis*, or other parasitoids divided by total number of larvae × 100, collected for individual sites. Means for *C. marginiventris*, *Ch. insularis*, or other parasitoids followed by the same letter are not significantly different, $P > 0.05$.

4. Discussion

Parasitism levels ranged from 1% in a commercial sweet corn field in Miami-Dade Co. to 91.7% in an unsprayed field on an agricultural experiment station in Palm Beach Co. Average parasitism across counties was similar to the rate in other studies of fall armyworm in corn, from the mid-teens (13.8%, Molina-Ochoa et al., 2004; 15.5%, Wheeler et al., 1989) to close to 40% (35%, Rios-Velasco et al., 2011; 39% Murúa et al., 2006). Hendry Co. had the lowest level of parasitization while the highest was at Palm Beach-EREC. The Hendry Co. location contained continuous plantings of vegetables, and therefore insecticide applications were frequent. Structurally most of the habitat was in commercial production, and although there were irrigation canals with non-sprayed plants in between crop plantings, overall plant diversity was relatively low. The Palm Beach-EREC site has approximately 325 ha composed of sugarcane, vegetables including sweet corn, turf, and fallow land with flowering plants along irrigation canals. Insecticide use was more infrequent compared to the other locations. Higher parasitism of fall armyworm has been related to more plant-diverse habitats (Molina-Ochoa et al., 2004).

Chelonus insularis and *C. marginiventris* were two of the three most commonly collected species from south Florida in the 1980s (Ashley et al., 1982, 1983; Pair et al., 1986a). It is not known why the third species, *T. difficilis*, was not found during our sampling. *Ch. insularis* appears to be the most geographically-dispersed parasitoid of fall armyworm in the U.S., Mexico, and South America. In Mexico, *Ch. insularis* and other *Chelonus* species were collected from 27 of the 32 states (González-Maldonado et al., 2014). Molina-Ochoa et al. (2003) lists 12 other countries in the Caribbean, Central America, and South America where there are collection records. In many of these areas, *Ch. insularis* was not only present but was the most common species collected (Wheeler et al., 1989; Cortez-Mondaca et al., 2010, 2012; Rios-Velasco et al., 2011; Estrada-Virgen et al., 2013). In non-tropical areas, there was evidence of northward movement of this parasitoid (Pair et al., 1986a). In the southeastern U.S., *Ch. insularis* seems to be most effective in south Florida and is only of secondary importance in north Florida and beyond (Ashley et al., 1982; Pair et al., 1986a). *Cotesia marginiventris* also has a wide geographic range, with records from 11 countries documented (Molina-Ochoa et al., 2003). This parasitoid is successful in subtropical and warm temperate areas such as in the southeastern U.S. (Ashley et al., 1982; Pair et al., 1986a; Riggin et al., 1992).

Chelonus insularis is typical of egg-larval solitary koinobiont endoparasitoids that oviposit into host eggs (Pierce and Holloway, 1912; Rechav and Orion, 1975) and survive through several molts until emerging from either 4th or 5th instar *Spodoptera* spp. host larvae that are actually developmentally arrested precocious prepupae (Ashley, 1983; Soller and Lanzrein, 1996; Pfister-Wilhelm and Lanzrein, 2009). These parasitized host larvae exhibit reduced growth rates and weight compared to unparasitized larvae (Ables and Vinson, 1981; Ashley, 1983). *Chelonus* spp. can "pseudoparasitize" hosts by initiating physiological factors after oviposition into host eggs that lead developing host larvae to precociously spin cocoons even if parasitoid development does not occur (Jones, 1985, 1986; Grossniklaus-Bürgin and Lanzrein, 1990). In terms of biological control, the results of pseudoparasitism, while perhaps not adding to the next generation of parasitoids, adds to additional mortality of pest larvae.

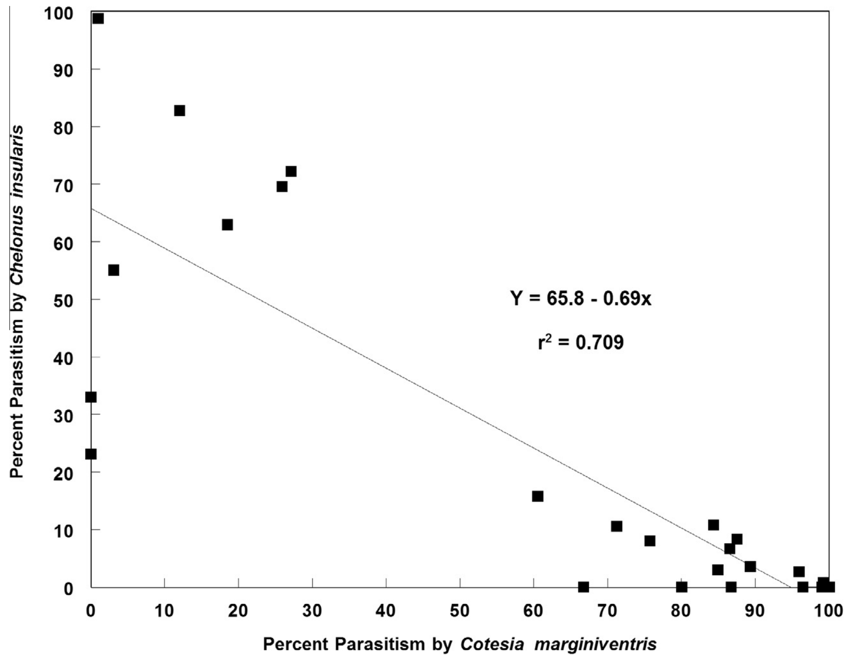

Fig. 3. Regression of percent parasitism attributed to *C. marginiventris* by percent parasitism attributed to *Ch. insularis* ($F = 56.7$; d.f. = 1, 22; $P < 0.0001$). Percent parasitism calculated as number of *C. marginiventris* or *Ch. insularis* divided by total number of parasitoids × 100, which emerged for individual sites.

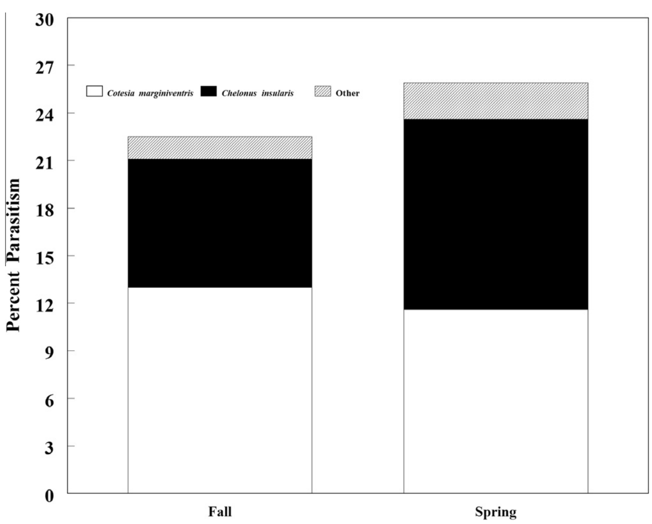

Fig. 4. Percent parasitism indicated by the number of *Cotesia marginiventris*, *Chelonus insularis*, or other parasitoids that emerged from fall armyworm larvae collected from sweet corn habitats in the "fall" (November or December) or "spring" (February, March, or April) in several sites in south Florida, 2010–2015. Percent parasitism calculated as number of *C. marginiventris*, *Ch. insularis* or other parasitoids divided by total number of larvae × 100, collected for individual sites within seasons. Means were not significantly different, $P > 0.05$.

Cotesia marginiventris is a solitary koinobiont endoparasitoid attacking chiefly 1st- and 2nd-instar larvae (Boling and Pitre, 1970; Loke et al., 1983), although facultative parasitism of host eggs has also been documented (Ruberson and Whitfield, 1996). Adult wasps emerge from 4th-instar larvae and these larvae reach only about 3% of their maximum weight when compared to unparasitized larvae (Ashley, 1983). Females are attracted to host larvae by orienting to both larval frass and host-induced plant volatiles (Loke et al., 1983; Loke and Ashley, 1984). Suboptimal and optimal host species can be attacked from a wide range of noctuid lepidopterans, but experience of ovipositing females on optimal host larvae increases their attraction and host-finding to these species (Tamò et al., 2006; Harris et al., 2012). Therefore, it appears that *C. marginiventris* can persist at low population densities on alternate hosts (Tingle et al., 1978; Johanowicz et al., 2002) but can then increase its populations when an optimal host such as fall armyworm becomes abundant. It should be noted that the identification of *C. marginiventris* may be questionable as several other very similar species have been reared from fall armyworm and the genus needs revision (R. Kula, USDA-ARS Systematic Entomology Laboratory, Beltsville, MD; personal communication). We are using the name *C. marginiventris* because of its long-time use in the literature on biological control of noctuid species.

The negative regression between parasitism by *C. marginiventris* and *Ch. insularis* suggests that one species is a better competitor than the other. In laboratory studies, parasitism of larvae was 2–4 times higher by *C. marginiventris* that had been previously parasitized by *Ch. insularis* as eggs, depending on larval host plant, indicating that *Ch. insularis* was not able to successfully compete against *C. marginiventris* (Rajapakse et al., 1991). Further, *C. marginiventris* females showed no host discrimination between larvae previously parasitized by *Ch. insularis* or unparasitized larvae, and *C. marginiventris* females obtained their maximum reproductive potential by parasitizing fall armyworm larvae previously attacked by *Ch. insularis* (Rajapakse et al., 1992). More research needs to be completed in field situations to better understand the interaction between these two species.

Insecticides comprise the major tactic used by growers to manage fall armyworm in sweet corn commercial production in south Florida (Ozores-Hampton et al., 2014). Insecticide treatments are applied to whorl-stage corn to prevent damage to developing tassels and upper leaves (Gross et al., 1982; Marenco et al., 1992), and to reduce numbers of the next generation that could damage corn ears. Our results suggest that *Ch. insularis* is more impacted than *C. marginiventris* by insecticide applications. Many insecticides are toxic to developing and adult *C. marginiventris* (Wilkinson et al., 1979; Atwood et al., 1997; Tillman and Scott, 1997; Pietrantonio and Benedict, 1999; Tillman and Mulrooney, 2000) and *Ch. insularis* wasps (Penagos et al., 2005; Zenner et al., 2006), either through direct toxicity of the insecticides or due to death of the host. If applications are not made directly to adult wasps, it appears that adult emergence from parasitized larvae may not be affected by host larvae feeding on plant material previously treated with insecticides (Atwood et al., 1998). Surprisingly, direct comparison of insecticide susceptibility with both species, both in application of insecticides to adults and feeding of parasitized larvae with treated host plant material, has not been done and should be a feature of future research.

Corn plants and the growers who produce them could derive a direct benefit from the actions of parasitoids that reduce feeding and lower weight gain of fall armyworm larvae (Fritzsche-Hoballah and Turlings, 2001; Hoballah et al., 2004). Therefore, strategies need to be developed to enhance the effectiveness of parasitoids against larvae attacking whorl-stage sweet corn. One strategy that has been proposed is to use "resource management" tactics to improve conditions for natural enemies (Lewis and Nordlund, 1980). Higher populations of generalist predators and parasitoids in agricultural landscapes were enhanced by the addition of flowering plants (Menalled et al., 2003; Díaz et al., 2012; Letourneau et al., 2012). Flowering plants can provide additional carbohydrate sources which increase parasitoid fecundity (Johanowicz and Mitchell, 2000; Riddick, 2007) and serve as food for alternative lepidopteran hosts for parasitoids that also attack fall armyworm (Tingle et al., 1978; Johanowicz et al., 2002). Fortunately, there is good preliminary information in Florida indicating potentially attractive flowering plants for *Ch. insularis* and *C. marginiventris* (Johanowicz and Mitchell, 2000; Rohrig et al., 2008; Sivinski et al., 2011). Additional research in agricultural habitats with flowering plants and the two braconid parasitoids will aid in developing a conservation biological control program targeted to manage fall armyworm populations in whorl-stage sweet corn.

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