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Parasitoids of *Prodiplosis longifila* Gagné (Diptera: Cecidomyiidae) and other Cecidomyiidae species in Colombia

Parasitoides de *Prodiplosis longifila* Gagné (Diptera: Cecidomyiidae) y otras especies de Cecidomyiidae en Colombia

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Abstract

Several species of *Synopeas* Förster (Hymenoptera: Platygasteridae) are parasitoids of gall midges and bud (Diptera: Cecidomyiidae) worldwide. In Neotropical region, the bud *Prodiplosis longifila* Gagné causes severe economic losses, particularly in tomato (*Solanum lycopersicum* L.) crops. *Prodiplosis longifila* is found in North and South America, and it is a potentially invasive species that is also found throughout Caribbean Islands. To diminish the impact of *P. longifila* on crops and to delay its geographical expansion it is necessary to identify its natural enemies and to improve its biological control. As a first step in this direction, in this study, four species of *Synopeas*: *S.* aff. *curvicauda, S.* aff. *longiventre, S. reticulatifrons* and *S. varipes* were collected from *Prodiplosis longifila*, *Prodiplosis floricola* and *Dasineura* sp. larvae sampled on Solanaceae crops (*Solanum lycopersicum, Capsicum annuum* and *C. frutescens*) and Tahiti lime (*Citrus* ˣ *latifolia*) in Colombia. Parasitoid species were identified based on morphological characteristics. Results indicate that *Synopeas* species can parasitize species of both *Prodiplosis* Felt and *Dasineura* Rondani genera and they are potential biological control agents to integrate into pest managements strategies against *P. longifila.*

Keywords: Biological control, *Citrus* ˣ *latifolia*, *Capsicum annuum*, *Solanum lycopersicum* L., *Dasineura*, *Prodiplosis*, *Synopeas.*

Resumen

Varias especies de *Synopeas* Förster (Hymenoptera: Platygasteridae) son parasitoides de cecidómidos (Diptera: Cecidomyiidae). En la región Neotropical, el cecidómido *Prodiplosis longifila* Gagné causa grandes pérdidas económicas, particularmente en cultivos de tomate (*Solanum lycopersicum*). *Prodiplosis longifila* es una especie potencialmente invasiva que se encuentra distribuida en Norte América, Sur América y las islas del Caribe. Para disminuir el impacto económico de *P. longifila* en cultivos, retrasar su expansión geográfica y mejorar su control biológico, es necesario la identificación de enemigos naturales potenciales. Como una primera aproximación en esta dirección, en este estudio, cuatro especies de *Synopeas* (*S.* aff. *curvicauda, S.* aff. *longiventre, S. reticulatifrons* and *S. varipes*) fueron obtenidas a partir de larvas de *P. longifila*, *P. floricola* y *Dasineura* sp. colectadas en cultivos de solanaceas (*Solanum lycopersicum, Capsicum annuum* y *C. frutescens*) y limón Tahiti (*Citrus* ˣ *latifolia*) en Colombia. Las especies de parasitoides fueron identificadas con base en características morfológicas. Los resultados indican que las especies de *Synopeas* pueden parasitar tanto al género *Prodiplosis* Felt como al género *Dasineura* Rondani y son agentes de control biológico potenciales para incorporar a las estrategias de manejo integrado de *P. longifila.*

Palabras clave: Control biológico, *Citrus* ˣ *latifolia*, *Capsicum annuum*, *Solanum lycopersicum, Dasineura*, *Prodiplosis*, *Synopeas.*

Introduction

The bud midge *Prodiplosis longifila* Gagné (Diptera: Cecidomyiidae) is a severe pest mainly of Solanaceae crops in South America, causing economic losses in potato (*Solanum tuberosum* L.) in Peru (Kroschel, Mujica, Alcazar, Canedo & Zegarra, 2012) and tomato (*Solanum lycopersicum* L.) in Ecuador (Valarezo, Cañarte, Arias, Proaño, Navarrete, Garzón, Jines, Cuadros, Porro, Linzán & Chávez, 2003) and Colombia (Hernández *et al.,* 2015). Besides Solanaceae crops, *P. longifila* causes losses to asparagus (*Asparagus officinalis* L.) (Asparagaceae) crops in Peru (Goldsmith, Castillo & Clarke-Harris, 2013) and to flower buds of Tahiti lime (*Citrus* ^{x} *latifolia* Tanaka ex Q. Jiménez) (Rutaceae) orchards in the United States (Florida) (Peña, Duncan & Torres, 1990). Recently, it was reported feeding on floral buds of Tahiti lime in Colombia (Hernandez, Guzman, Martínez, Manzano & Selvaraj, 2015). Because of severity of its damage on traded fruits such as tomatoes, *P. longifila* was included recently in European and Mediterranean Plant Protection Organization alert list (European and Mediterranean Plant Protection Organization, EPPO; *https://gd.eppo.int/taxon/PRDILO*). In addition, *P. longifila*, other cecidomyiid species belonging to genus *Dasineura* can cause economic losses to several crops around the world such as *Dasineura mali* K. on apple *Malus pumila* Mill. (Rosaceae) (Hall, Amarawardana, Cross, Francke, Boddum & Hillbur, 2012) and *Dasineura oxycoccana* (Johnson) on cultivated blueberries *Vaccinium corymbosum* L. (Ericaceae) (Sampson, Rinehart, Liburd, Stringer & Spiers, 2006). *Prodiplosis floricola* Felt feeds on floral buds of *Spiraea salicifolia* L. (Rosaceae) and *Clematis* sp. (Ranunculaceae) in the United States (Gagné & Jaschhof, 2014) and it causes economic damage to *Caryocar brasiliense* Cambess. (Caryocaraceae) in Brazil (Gagné & Jaschhof, 2014). Recently *P. floricola* was reported feeding on Tahiti lime floral structures in Colombia (Duque-Gamboa, 2017. In Press.).

P. longifila larvae feed on leaf buds, flowers and immature tomato fruits and on flowers and flower buds of Tahiti lime (Peña, Duncan & Torres, 1990; Hernandez *et al.,* 2015) and consumes the epidermis tissue of asparagus shoots (Goldsmith, Castillo & Clarke-Harris, 2013). Control of *P. longifila* on different crops include adult mass trapping using light and color traps (Goldsmith, Castillo & Clarke-Harris, 2013), physical control with high pressure water to remove adults (Goldsmith, Castillo & Clarke-Harris, 2013) but chemical spray is the principal control method used (Valarezo *et al.,* 2003; Kroschel *et al.,* 2012). In relation to biological control several natural predators have been reported (Valarezo *et al.,* 2003; Goldsmith, Castillo & Clarke-Harris, 2013).

Taxonomic studies on native parasitoids attacking *P. longifila* have been largely neglected. Unidentified *Synopeas* species have been reported to act as natural enemies of *P. longifila* on tomato (Valarezo *et al.,* 2003), Tahiti lime (Peña, Duncan & Torres, 1990) and asparagus (Goldsmith, Castillo & Clarke-Harris, 2013).

Synopeas females are shiny micro wasps (1-2 mm) characterized by having cylindrical antennae and by lacking wing veins (Buhl, 1997). They are koinobiont endoparasitoids of eggs and early larval stages of Cecidomyiidae (Austin, Johnson & Dowton, 2005). Adult wasps emerge during the prepupal or pupal stage of the host (Masner & Arias-Penna, 2006). Biological information is limited (Abram, Haye, Mason, Cappuccino, Boivin & Kuhlmann, 2012; Sampson *et al.,* 2006).

Because of the economic impact of *P. longifila*, the aim of this study was to survey parasitized *P. longifila* (and other cecidomyiid species) on bell pepper (*Capsicum annuum* L.), chili pepper (*Capsicum frutescens* L.), tomato and Tahiti lime in Colombia, to quantify and reveal the taxonomic identity of emerging parasitoid species.

Materials and methods

Cecidomyiidae

To determine the presence of Cecidomyiidae (and its parasitoids), plantations of bell pepper, chili pepper, Tahiti lime and tomato were sampled in the departments of Antioquia, Boyacá, Caldas, Cauca, Cundinamarca, Huila, Nariño, Quindío, Risaralda, Santander and Valle del Cauca in Colombia (Figure 1).

Plant structures containing Cecidomyiidae were collected from each crop. For tomato, leaves, flowers and fruit were collected; for Tahiti lime, flower buds were collected; and for bell pepper and chili pepper, immature fruits were collected. Every sample location was georeferenced by using a Global Positioning System (GPS; GPSmap 60CSx, Garmin), and the presence/absence of Cecidomyiidae was determined. Plant structures containing larvae were removed and placed in plastic containers (20 x 10 x 5 cm) along with wet napkins to avoid desiccation. Containers were transported to the Laboratory of Entomology and Acarology of the Universidad Nacional de Colombia, Palmira campus and placed into growth chambers (Panasonic MLR-351) under controlled conditions [23°C and 75% relative humidity (RH)]. Adults of the pest species were identified microscopically according to Gagné (1994).

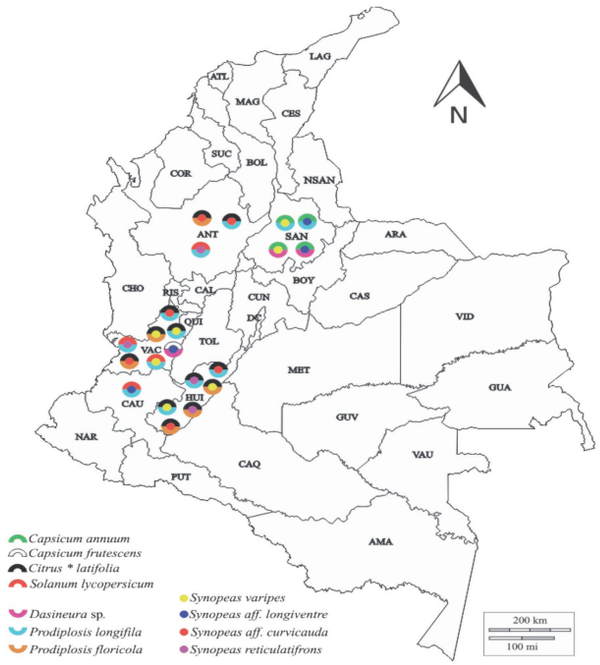

Figure 1. Map of Colombia showing tritrophic interactions in sampled sites. The superior and inferior circumference segments correspond to plant host and insect host respectively. The central point corresponds to parasitoid species.

Parasitoids

The Cecidomyiidae larvae that did not develop to adults and showed symptoms of being parasitized (pale green color in the middle section of the larvae and translucent pupae, Figure 2), were retained in controlled-environment chamber until emergence of their parasitoids. Emerged parasitoids were placed in 75% alcohol for one hour, and then maintained refrigerated at -10°C for three days. They were then pinned with micro-entomological pins. Morphospecies were classified using dichotomous keys for family (Masner & Arias-Penna, 2006) and species (Buhl, 2011). A representative specimen of each species was photographed with a camera and attached to a compound stereoscope (SMZ-445), and several pictures of each specimen were taken from different perspectives.

Multifocal compositions were created using the software CombineZP (*http://www.hadleyweb.pwp.blueyonder.co.uk*/). Parasitoid taxonomic identification was carried out by P. Buhl. Specimens were deposited in the Entomological Museum of the Universidad Nacional de Colombia, Palmira (CEUNP).

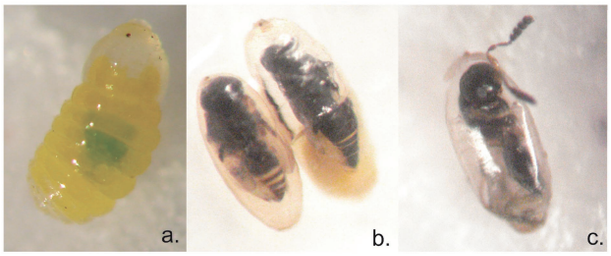

Figure 2. Symptoms of immature stages of *Prodiplosis longifila* parasitized: a: initial symptom on a parasitized larva, b: parasitoid development on pupae and c: parasitoid emergence. Magnification 35x.

Parasitoid searching behavior

For Tahiti lime orchards, a photographic record was obtained (Panasonic Lumix DMC-LX5), and the behavior of *Synopeas* aff. *curvicauda* on the flower buds was observed.

Data Analysis

Assuming a similar sampling effort by each crop batch and based on the presence of *Prodiplosis* spp. in all crops, the abundance of recovered parasitoids by host crop was obtained and parasitoid preference for a host crop was determined using X^2 analysis (null hypothesis of parasitoid equal preference). Due to the fact that some parasitoid species were not recovered from certain crops (values = zero) the Yates' continuity correction for X^2 was used (Daya, 2001).

Results

From 168 batches of crops located between 739 and 2973 m.a.s.l. in the Andes and interandean valleys, the larvae of Cecidomyiidae were found on chili pepper, Tahiti lime, bell pepper and tomato; however, they were not found on asparagus or potato. The presence of *P. longifila* (on tomato, bell pepper and Tahiti lime), *Prodiplosis floricola* (on Tahiti lime) and *Dasineura* sp. (on chili pepper and bell pepper) was confirmed. Examination of 157 parasitoid specimens grown in the laboratory yielded four identified species: *Synopeas varipes* Harrington (1900) (Figure 3 a,b), *Synopeas reticulatifrons* Buhl (2011), (Figure 3 c,d), *Synopeas* aff. *longiventre* Ashmead (1893) (Figure 3f) and *Synopeas* aff. *curvicauda* Föster (1856) (Figure 3e) (Table 1). Parasitoids appeared 15 days after Cecidomyiidae in plantations in which farmer had stopped using insecticides.

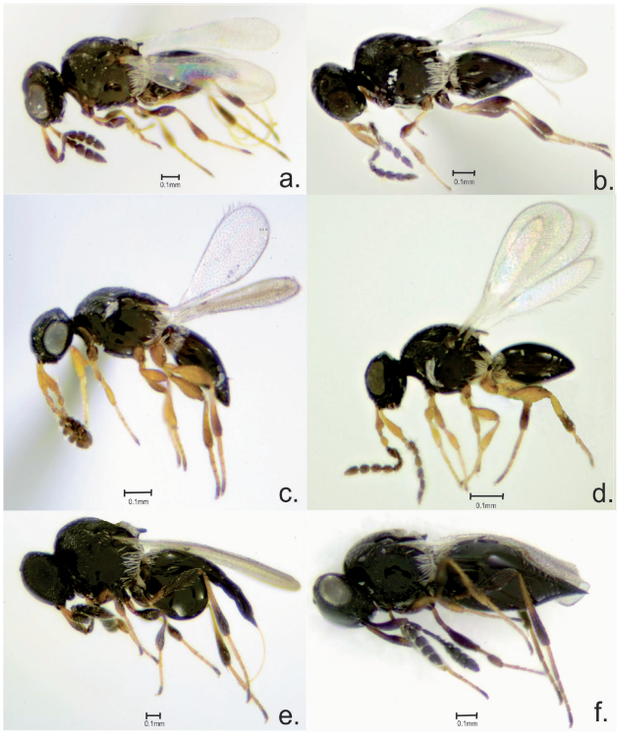

Figure 3. Parasitoid wasp species found: *Synopeas varipes*: female (a.), male (b.); *Synopeas reticulatifrons*: female (c), male (d); *Synopeas* aff. *longiventre*: female (f); *Synopeas aff. curvicauda*: female (e).

Table 1. Number of parasitoids recovered from *Prodiplosis* spp. larvae collected in bell pepper, Tahiti lime and tomato crops.

Parasitoid species	Host crop		
	Capsicum annum	*Citrus x latifolia*	*Solanum lycopersicum*
Synopeas* aff. *curvicauda	0	17	0
Synopeas* aff. *longiventre	6	0	1
Synopeas reticulatifrons	0	5	45
Synopeas varipes	9	25	48

Figure 4. *Synopeas aff. curvicauda* on Tahiti lime flower buds.

Synopeas varipes Harrington, 1990

Examined material

Colombia, Huila; 4♂♂, 3♀♀; El Agrado, La Yagilda, 2°14'4.5"N, 75°43'56.0"W, 784 m.a.s.l.; 13.II.2013; *Prodiplosis* (*P. longifila* and/or *P. floricola*) larvae collected from *Citrus x latifolia* in growth chambers coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP); Huila; 2♂♂, 2♀♀; Garzón, La Junga, 2°14'4.5"N, 75°43'56.0"W, 784 m.a.s.l.; 14.II.2013; *Prodiplosis* (*P. longifila* and/or *P. floricola*) larvae collected from *Citrus x latifolia* in growth chambers, coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP). Huila; 1♂, 1♀; Garzón, La Galda, 2°9'38.8"N, 75°43.0'56"W, 784 m.a.s.l.; 14.II.2013; *Prodiplosis* (*P. longifila* and/or *P. floricola*) larvae collected from *Citrus x latifolia* in growth chambers, coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP). Santander; 4♂♂, 5♀♀; Lebrija, La Laguna, 7°5'57.5" N, 73°12'54.6"W, 1098 m.a.s.l.; 12.VI.2012; *P. longifila* and/or *Dasineura* sp. larvae collected from *Capsicum annuum* in growth chambers; L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP). Valle del Cauca; 27♂♂, 17♀♀; Universidad Nacional de Colombia, Palmira campus, 3°30'42.6"N, 76°18'20.8"W, 998 m.a.s.l.; 3.VI.2012; *P. longifila* larvae collected from *S. lycopersicum* in growth chambers, coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (CEUNP). Valle del Cauca; 6♂♂, 4♀♀; Zarzal, Las Lajas, 4°24'41.2"N, 76°3'20.6"W, 974 m.a.s.l.; 1.II.,2014; *Prodiplosis* (*P. longifila* and/or *P. floricola*.) larvae collected from *Citrus x latifolia* in growth chambers, coll, L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP). Valle del Cauca; 1♂, 3♀♀; Candelaria, Experimental Center of Universidad Nacional de Colombia, Palmira campus (also named CEUNP), 3°24'27.1"N, 76°25'6.9"W, 971 m.a.s.l.; 24.IV.,2012; *P. longifila* larvae collected from *S. lycopersicum* in growth chambers, coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP). Antioquia; 2♀♀; Támesis, San Isidro, 5°41'9.2"N, 75°41'25.2"W, 1162 m.a.s.l.; 2.V.2013; *Prodiplosis* (*P. longifila* and/or *P. floricola)* larvae collected from *Citrus x latifolia* in growth chambers; coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP).

A total of 82 specimens of *Synopeas varipes* were collected on tomato (48 specimens), Tahiti lime (25 specimens) and bell pepper (9 specimens). Abdomen of the female of the species *Synopeas varipes* is characterized by the terminal segments forming a deflected tail and the presence of a small sharp scutellar spine. Male can be distinguished by the shape of the abdomen and antennae (Figures 3 a, b, 5a-e). *Synopeas. varipes* was found in every plantation except chili pepper plantations, and it was especially abundant on Tahiti lime (42 specimens), where it was found together with *S.* aff. *curvicauda* on flower buds (Figure 5). Eighty-three specimens of this species

were found in all of the plantations. Adults are black and microscopically perforated and have a pale scape. Scutellum has a small sharp spine; the sides of the basal part of the abdomen are hairy and silver in color; legs are brown with yellowish tibia and tarsus; second sternite is clearly convex, and the last is perforated. In males, the last sternite is shorter than the second sternite. The maximum length of the body is 1.1 mm, and head is uniform and clearly perforated (Buhl, 2011).

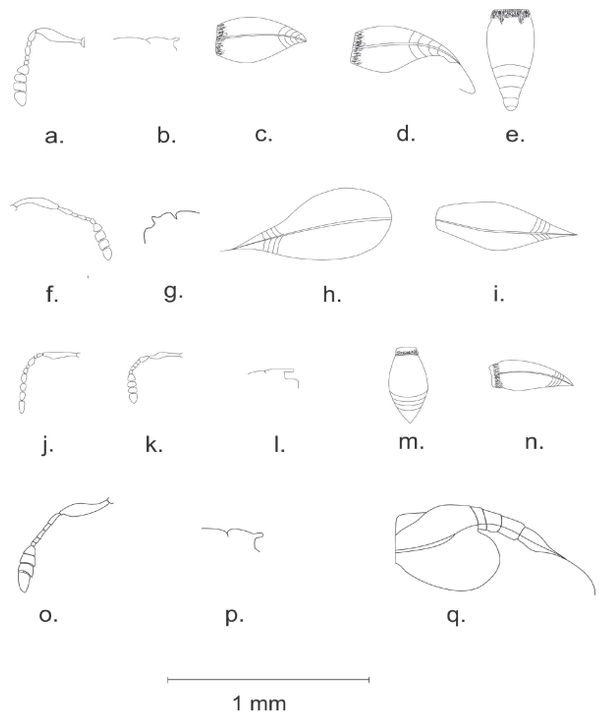

Figure 5 Diagram showing the observed parasitoids

– e. *Synopeas varipes*: a. antenna ♀; b. scutellar spine; c. abdomen ♂ (lateral view); d. abdomen ♀ (lateral view); e. abdomen ♀ (dorsal view); f. – i. *Synopeas aff. longiventre*: f. antenna ♀; g. scutellar spine; h. abdomen ♀; i. abdomen ♂; j. – n. *Synopeas reticulatifrons*: j. antenna ♂; k. antenna ♀; l. scutellar spine; m. abdomen ♀ (dorsal view); n. abdomen ♀ (lateral view); o. – q. *Synopeas aff. curvicauda*: o. antenna ♀; p. scutellar spine; and q. abdomen ♀. Scale = 1.00 mm.

Synopeas aff. *longiventre* Ashmead, 1893

Examined material

Colombia, Santander; 4♂♂, 2♀♀; Lebrija, La Laguna, 7°5'57.5"N 73°12'54.6"W, 1098 m.a.s.l.; 12.VI.2012; *Dasineura* sp. and/or *P. longifila* larvae collected from *C. annuum* in growth chambers, coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP). Cauca; 1♂; Cajibio, La Viuda, 2°33'33.7''N, 76°34'39.8"W, 1763 m.a.s.l; 5.IV,2013; *P. longifila* larvae collected from *S. lycopersicum* in growth chambers, coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP). Valle del Cauca; 1♂; Roldanillo, Santa Rita, 04°28'04.0"N, 76°07.0'18.1"W, 939 m.a.s.l; 7.IX,2012; *Dasineura* sp. larvae collected from *C. frutescens* in growth chambers, coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP).

A total of 8 specimens of this species were collected on tomato (1 specimen), bell pepper (6 specimens) and chili pepper (1 specimen). The identity of *S.* aff. *longiventre* should be elucidated in order to determine whether thus is a new species because it is similar to *S. longiventre*. Female of *S.* aff. *longiventre* has an abdomen that is twice as long as thorax and partially compressed when observed dorsally, and scutellum has a very small spine (Figures 3f, 5f-i). The antennae have 10 segments (Figure 5f), which are covered by filaments in males.

Synopeas reticulatifrons Buhl, 2002

Examined material

Colombia, Valle del Cauca; 18♂♂, 22♀♀; National University of Colombia, Palmira campus, 3°30'42.6''N, 76°18'20.8''W, 998 m.a.s.l.; 3.VII.2012, *P. longifila* larvae collected from *S. lycopersicum* in growth chambers, coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP). Valle del Cauca; 3♂♂, 1♀; Candelaria, Experimental Center of the National University of Colombia, Palmira campus (Museum ECNUP), 3°24'27.1"N, 76°25'06.9''W, 971 m.a.s.l.; 16.IV.2012; *P. longifila* larvae collected from *S. lycopersicum* in growth chambers; coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP). Huila; 2♂♂, 1♀; Garzon, La Galda, 2°14'4.5"N, 75°43'56.0"W, 784 m.a.s.l.; 13.II.2013, *Prodiplosis* (*P. longifila* and/or *P. floricola*) larvae collected from *C.* x *latifolia* in growth chambers; L. Miguel Hernandez, Yoan Camilo Guzman, Maria R. Manzano (Museum CEUNP). Huila; 1♂, 1♀; Garzon, La Junga, 2°14'4.5"N, 75°43'56.0"W, 784 m.a.s.l.; 13.II.2013, *Prodiplosis* (*P. longifila* and/or *P. floricola*) larvae collected from *C.* x *latifolia* in growth chambers; L. Miguel Hernandez, Yoan Camilo Guzman, Maria R. Manzano (Museum CEUNP). Antioquia; 1♂; Marinilla, 06°09'54.4"N, 075°20'05.3"W, 2178 m.a.s.l.; 29.II.2013, *P. longifila* larvae collected from *S. lycopersicum* in growth chambers; coll. L. Miguel Hernandez, Yoan Camilo Guzman, Maria R. Manzano (Museum CEUNP).

A total of 50 specimens of this species were collected on tomato (45 specimens) and Tahiti

lime (5 specimens). Adults are black in color, the abdomen is almost as long as the head and thorax combined and slightly wider than the thorax; and the scutellar spine is longer than the propodeum and has a translucent end (Figures 3 c,d; 5 l-n). The males of this species are differentiated from the females by their antennae: the apical segments of males are longer than they are wide (Figure 5j, k).

***Synopeas* aff. *curvicauda* Förster, 1856**

Examined material

Colombia, Valle del Cuaca; 5♀♀; Palmira, Corporación Colombiana de Investigación Agropecuaria (CORPOICA), 3°30'45.7''N, 76°18'53.1"W, 1006 m.a.s.l.; 16.V.2012; directly collected from flower buds of Tahiti lime trees, coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (CEUNP). Valle del Cauca; 3♂♂, 5♀♀; Zarzal, Las Lajas, 4°24'41.2"N, 76°3'20.6"W', 974 m.a.s.l.; 14.II.2014; *Prodiplosis* (*P. longifila* and/or *P. floricola*) larvae collected from growth chambers; coll, L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP). Huila; 2♂♂, 1♀; Garzón, La Junga, 2°9'38.8"N, 75°39'36.8"W, 739 m.a.s.l.; 14.II.2013; *Prodiplosis* (*P. longifila* and/or *Prodiplosis floricola*) larvae collected from *C.* x *latifolia* in growth chambers, coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (Museum CEUNP). Antioquia; 1♀; Tamesis, San Isidro, 5°42'09.0"N, 75°40'24.8"W, 845 m.a.s.l.; 2.V.2013, *Prodiplosis* (*P. longifila* and/or *P. floricola*) larvae collected from *Citrus* x *latifolia* in growth chambers; coll. L. Miguel Hernández, Yoan Camilo Guzmán, Maria R. Manzano (CEUNP).

A total of 17 specimens of this species were collected on Tahiti lime. It is important to confirm whether *Synopeas* aff. *curvicauda* is new because it is similar to *S. curvicauda* (but with shorter basal flagellar segments in the female). This species was observed only on Tahiti lime (16 specimens) where both *P. longifila* and *P. floricola* were found. However, it is unknown if both *P. longifila* and *P. floricola* are parasitized by *Synopeas aff. curvicauda* Förster. The adults are black with uniformly perforated head (Figure 3e); female abdomen is 1.6 times longer than the head and thorax combined but narrower than the thorax (Figure 3e). Antennae and scutellar spine are shown in Figures 3, 5. The main feature of the abdomen is its comma shape (Figures 3e, 5o-q).

Parasitoid searching behavior

In Tahiti lime orchards, *Synopeas* aff. *curvicauda* wasps were observed walking on flower buds using their antennae to locate the small space formed in the flower bud corolla to place the ovipositor and lay eggs (Figure 4).

Parasitoid-plant association

Numbers of parasitoids recovered from *Prodiplosis* species collected on different host plants are presented in Table 1. Parasitoid species were not equally found on all host plants (X^2 *(continuity)* = 93.11, df = 6, P < 0.05). *Synopeas varipes* and *S. reticulatifrons* were the most abundant species (84.6% of total recovered parasitoids) and they were associated mainly to tomato. On Tahiti lime three parasitoid species were found (30.1% of total recovered parasitoids) and *Synopeas* aff. *curvicauda* was found only on this crop (10.9% of total recovered parasitoids).

Discussion

In this study, four *Synopeas* species (*Synopeas* aff. *curvicauda Synopeas* aff. *longiventre*, *S. reticulatifrons* and *Synopeas. varipes*) were collected from three different host species of Cecidomyiidae (*Prodiplosis longifila*, *P. floricola* and *Dasineura* sp.) living on three commercial species of Solanaceae (tomato, chili pepper and bell pepper) and on Tahiti lime. In the New World information about *Synopeas*-host interaction is not complete.

On one hand *Synopeas* hosts have not been identified. Several *Synopeas* species have been described in temperate areas (Buhl, 1997; Buhl, 2011; MacGown & Evans, 2003) and a few in tropical areas such as Panama, Brazil and Costa Rica (Buhl, 2011) but mostly with unknown hosts. Because of the small size of cecidomyiid larvae which makes it difficult to separate species, it was not possible to clarify if *Synopeas* aff. *curvicauda* parasitizes both *P. longifila* and *P. floricola*. Molecular tools may be useful to improve these results (Hrcek, Miller, Quicke & Smith, 2011). On the other hand, the *Synopeas* species that regulate *P. longifila* in Peru, Ecuador (Valarezo *et al.*, 2003) and in USA (Peña, Duncan & Torres, 1990) remain unidentified.

In general, members of the superfamily Platygastroidea rarely parasitize a wide range of hosts (Austin, Johnson & Dowton, 2005). Abram *et al.* (2012), presented a complete revision of the species of Cecidomyiidae that are considered crop pests and confirmed a low specificity between *Synopeas* and their Cecidomyiidae hosts. For example, species such as *Synopeas myles* (Walker) is able to parasitize five Cecidomyiidae species of the genera *Contarinia* and *Dasineura* (Abram *et al.,* 2012). Similarly, *S. varipes,* found in the present study parasitizes *P. longifila* in

tomato, *Dasineura* sp. on chili pepper and the *P. longifila – P. floricola* complex on Tahiti lime. Moreover, *S. varipes* is also a parasitoid of *D. mali* on apples (Buhl, 1997). Although our study did not test parasitoid attraction some hypothesis may explain our results.

Firstly, *Prodiplosis* and *Dasineura* feed on plant tissue by scraping the epidermal tissues of plant structures using piercing-sucking mouthparts (Gagné, 1994) and this damage could induce volatile production which can be detected by parasitoids. For Brassicaceae species it was found that volatile emissions are very similar when plant are damaged by different herbivores and parasitoids cannot detect these differences (Gols & Harvey, 2009). For example our results show that *S.* aff. *curvicauda* was found only on Tahiti lime where *P. longifila* and *P. floricola* coexist in the same flower bud (Duque-Gamboa, 2017. In Press.) and probably producing similar attractive volatiles.

Synopeas curvicauda parasitizes *Contarinia solani* (Rübsaamen) on *Solanum dulcamara* L. blossoms and is probably attracted by its odors. Our field observations showed that *Synopeas* aff. *curvicauda* flew to Tahiti lime flower buds to detect and parasitize *Prodiplosis* larvae. Citrus blossoms produce volatile compounds such as linalool, β-myrcene, α-myrcene, limonene, (*E)*-ocimene, methyl anthranilate and indole, which are most likely involved in attracting other insects, such as pollinator bees (Jabalpurwala, Smoot & Rouseff, 2009). Females of *Synopeas* aff. *curvicauda* were observed on Tahiti lime orchards on flower buds while using their antennae repeatedly to locate the upper orifice before they began laying their eggs. The detection of chemical information by Platygastroidea appears to be conducted by one or two multiporous gustatory sensilla located in the lower part of the antennal clavus (Austin, Johnson & Dowton, 2005).

Our results revealed three *Synopeas* species (*Synopeas* aff. *longiventre,S. reticulatifrons,* and *S. varipes*) with potential as biological control agents of *P. longifila* on tomato given the threat of this pest for tomato trade. These species merit biological and behavioral studies before being selected for augmentative biological control programs (Van-Lenteren & Manzaroli, 1999) as they are key species to be studied for developing conservative biological control, an approach suggested for *Dasineura brassicae* on Brassicae in Europe including some Platygastridae species (Ulber, Williams, Klukowski, Luik & Nilsson, 2010). The value of biological control of *Synopeas* species against *P. longifila* was noted for Tahiti lime in the USA (Goldsmith, Castillo & Clarke-Harris, 2013) and *Synopeas* sp. was reared and released in asparagus in Peru to control *P. longifila*. Parasitoids are more specific than other biological control agents and therefore have restricted host ranges, which is an advantage to implement biological control programs (Van-Lenteren & Manzaroli, 1999). The finding and taxonomic identification of *Synopeas* species in the present study open a new opportunity to explore their potential to be used in IPM programs in order to reduce the high input of pesticides against *P. longifila* in the tropics (Valarezo *et al.,* 2003; Kroschel *et al.,* 2012). It is unknown if *P. longifila* or *P. floricola* cause economic damage to Tahiti lime orchards in Colombia (Hernandez *et al.*, 2015; Duque-Gamboa, 2017) and if that is the case, the results of the present study indicate that *Synopeas* aff. *curvicauda* would be the parasitoid species to be further investigated.

Conclusion

Four species of parasitoids (*S. varipes*, *Synopeas* aff. *longiventre*, *S. reticulatifrons* and *Synopeas* aff. *curvicauda*) were found associated with three cecidomyiid species (*Prodiplosis longifila, Prodiplosis floricola* and *Dasineura* sp.) in four crops (chili pepper, bell pepper, Tahiti lime and tomato) conforming a complex of plant-herbivore-parasitoid interactions. Parasitoid species were not equally found in all host plants (X^2 *(continuity)* = 93.11, df = 6, P < 0.05) and they were more abundant on tomato crops and Tahiti lime orchards. *Synopeas varipes* and *S. reticulatifrons* were the most abundant species (84.6% of total recovered parasitoids). *Synopeas* aff. *curvicauda* was the only parasitoid species found on Tahiti lime.

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