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Research Article

First record of *Encarsia formosa* Gahan, an aphelinid parasitoid of greenhouse whitefly from India and its dynamics on tomato grown under protected environment

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ABSTRACT: Greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) is a key pest of tomato under protected environment in Himachal Pradesh. Recently, an aphelinid parasitoid, *Encarsia formosa* Gahan was observed to parasitize *T. vaporariorum* in mid-hill regions of Himachal Pradesh. It seems to be the first record of this aphelinid parasitoid from India. Population buildup of *E. formosa* was recorded in eight insecticide based greenhouse whitefly management modules comprising soil application of imidacloprid (0.009%) and foliar applications of spiromesifen (0.02%), thiamethoxam (0.01%) and azadirachtin (0.0003%) in tomato grown during summer cropping seasons of 2015 and 2016 under naturally ventilated polyhouse. Parasitization by *E. formosa* in the plants without treatment varied from 31.8 to 81.2 and 36.8 to 93.6 per cent during 2015 and 2016, respectively. The insecticidal module comprising single soil application of imidacloprid one day after transplanting followed by alternate foliar applications of azadirachtin starting 45 days after transplanting at 10 days interval proved favourable for buildup of *E. formosa* as compared to other insecticide based greenhouse whitefly management modules during both the seasons. Based on the observations recorded, it was observed that the parasitoid has the potential for inclusion in greenhouse whitefly management programme.

KEY WORDS: *Encarsia formosa*, management, protected cultivation, *Trialeurodes vaporariorum*

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INTRODUCTION

The greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae) is a serious pest intemperate regions under protected cultivation situations and in field crops where the summers are warm enough (Byrne and Bellows, 1991; Sood and Sood, 2004). In Himachal Pradesh, eight insect and non-insect-pest species have been recorded associated with tomato under protected cultivation, amongst them; *T. vaporariorum* is the key pest (Sood *et al.,* 2012). Adults and nymphs of *T. vaporariorum* suck phloem sap and results in weakening of host plant, while their honeydew secretion creates favourable conditions for the development of sooty mould that reduces plant photosynthesis. Under protected environment, greenhouse whitefly breeds throughout year and completes thirteen generations in a year (Sood *et al.,* 2014). The favourable abiotic conditions and availability of tender plant parts for longer duration accompanied with more number of generations makes the management of *T. vaporariorum* more difficult. It needs more number of insecticidal applications to suppress the incidence, which leads to undesirable pesticide residues, killing of non-target organisms and development of resistance in *T. vaporariorum* to pesticides (van Lenteren, 2000; Sood *et al.,* 2006; Pilkington *et al.,* 2010; Pappas *et al.,* 2013). Recently, an aphelinid parasitoid, *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) was found parasitizing greenhouse whitefly nymphs at Palampur, representing mid-hills of Himachal Pradesh. *Encarsia formosa* is used worldwide for commercial control of whiteflies in greenhouse crops. The present investigations were conducted to study the effect of insecticide based modules being evaluated for the management of *T. vaporariorum* on build-up of *E. formosa* and to determine the relative safety of modules in tomato under protected environment.

MATERIALS AND METHODS

The aphelinid parasitoid was first noticed during 2014 in tomato crop planted under protected environment at Palampur, 1290 m asl, representing mid-hills of Himachal Pradesh. Black mummified nymphs of *Trialeurodes vaporariorum* observed on mature leaves were collected and brought to the laboratory for emergence of adult parasitoids (Figure 1). The emerged adults were collected and preserved in 70 per cent ethanol and sent to Dr Mohammad Hayat, Department of Zoology, Aligarh Muslim University, Aligarh, India, for determining the identity.

Fig. 1. A. Adult *Encarsia formosa*; B. Healthy and parasitized (black) nymphs of *Trialeurodes vaporariorum.*

Observations on buildup of *Encarsia formosa* were recorded in an experiment where insecticide based modules were being evaluated for the management of *T. vaporariorum.* Eight insecticide based modules comprising soil application of imidacloprid at transplanting and foliar applications of azadirachtin, spiromesifen and thiamethoxam were formulated (Table 1) and evaluated for the management of greenhouse whitefly on tomato grown under naturally ventilated polyhouse. All the insecticides evaluated were recommended and approved for use in tomato crop by Central Insecticides Board and Registration Committee, Government of India. The studies on extent of parasitization by *E. formosa* were undertaken in summer cropping season (March-July) during 2015 and 2016.

During 2015, activity of *E. formosa* was observed in eight management modules, where the adults of *T. vaporariorum* were released in large numbers at transplanting to initiate early buildup of the pest. Observations on parasitization of greenhouse whitefly immature (nymphs and pupae) were recorded 90 and 120 Days after Transplanting (DAT). Whereas, during 2016, four modules resulting in better suppression of greenhouse whitefly and higher tomato fruit yield were selected and evaluated. Also, adult greenhouse whiteflies were not released in early crop growth stage and the natural buildup of the pest was allowed. Observations on extent of parasitization of *E. formosa* were initiated with the first appearance of mummified immatures of greenhouse whitefly and continued till final harvesting of the crop at weekly interval.

Tomato cultivar Palam Tomato Hybrid-1 was raised in modified quonset naturally ventilated polyhouse (250 m^2) by transplanting one month old seedlings in raised beds (90 cm wide) with plant to plant and row to row spacing of 30 cm and 70 cm, respectively. Plants were trained on two stems. There were 24 plants in each management module (plot size: 4m×0.9m) which were replicated thrice in a randomized block design.

Healthy and mummified nymphs and pupae of greenhouse whitefly were counted in lower and middle plant canopy from randomly selected five plants and per cent parasitization was worked out as per the following formula:

Parasitization (%)

$$= \frac{\text{Number of mummified nymphs of greenhouse whitefly}}{\text{Number of healthy nymphs} + \text{Number of mummified nymphs}} \times 100$$

RESULTS AND DISCUSSION

Taxonomy

Encarsia formosa Gahan (Figure 2 (A-G))

Enacrsia formosa Gahan, 1924: 14, female. USA, Idaho, Twin Falls.

Encarsia formosa Gahan: Huang and Polaszek, 1998: 1881–1882, female, male, diagnosis, figures. Schmidt and Polaszek, 2007: 2165–2167, female, male, diagnosis, figures. Myartseva *et al*., 2012: 185–186, female, diagnosis, figures.

Diagnosis

Female. Length, 0.64–0.73 mm. Head dark brown, ocellar area blackish; post-ocellar bars blackish. Mandible apically dark brown. Antenna with scape pale yellow; pedicel brown; funicle pale yellow; clava with first segment yellow, second segment brown. Mesosoma dark brown, with expanded part of side lobe of mesoscutum white. Wings hyaline; fore wing with submarginal vein brown; costal cell in about basal half infuscate brown. Legs pale yellowish white; fore coxa basally brown; hind coxa in about basal third dark brown. Metasoma with petiole dark brown; gaster white, at most tergite 1 (TI) narrowly across base pale brown.

Head (Figure 2 A) with frontovertex width more than half of head width; head with the usual medio-frontal, transverse and lateral lines; sculpture and setation as in Fig. 2A; eye setose, setae hyaline, each seta longer than a facet diameter. Mandible (Figure 2 B) with 2 teeth and a dorsal truncation. Maxillary and labial palps each 1-segmented.

Antennal formula, 1142 (Figure 2 C); first funicle segment (F1) slightly shorter than to as long as pedicel, and about 2× as long as broad; F2–F4 each at least about 3× as long as broad, each clearly longer than F1; clava 2-segmented.

Mesosoma with sculpture as in (Figure 2 D and E); setae on tergites as follows: pronotal collar with 5 + 5 setae, and a long seta at each postero-lateral corner; mid lobe of mesoscutum with 18 setae; each side lobe with 3 setae; each axilla with 1 seta, situated near to mesal margin in anterior third; scutellum with 4 (2 + 2) setae, anterior pair separated by a distance slightly greater than distance between posterior pair; scutellar sensilla distantly placed, nearer to each anterior seta; propodeum with 2 setae distal to each spiracle. Fore wing (Figure 2 F) 2.6× as long as broad; marginal fringe 0.26× wing width; submarginal vein with 2 setae; one seta on parastigma; 8 setae on marginal vein; basal cell with 4 setae; marginal vein clearly longer than costal cell; postmarginal vein absent; stigmal vein thin. Hind wing (Figure 2 G) about 7.5× as long as broad; marginal fringe slightly longer than wing width. Mid leg (Figure 2 D) with tarsus 4-segmented; mid tibial spur slightly shorter than half the length of mid basitarsus.

Metasoma (Figure 2D) with petiole smooth; gaster with setae on tergites 1–7 (TI–TVII) as follows: TI, 0 + 0; TII–TIV, 1 + 1 each; TV, 1 + 2 + 1; TVI, 1 + 2 + 1 (outer seta each situated proximal to cercal plate, and 2 setae median); TVII, 4; ovipositor with second valvifer 1.54× as long as third valvula (ovipositor subequal in length to mid tibia; third valvula slightly longer than mid basitarsus, and 2.33× as long as mid tibial spur).

Male Not obtained in our collection.

Material examined: Several females, with 11 females on 5 slides (slide Nos. 641.E–645.E): INDIA: Himachal Pradesh: Palampur, 14.ix.2016, coll. Vinay Singh. ex *Trialeurodes vaporariorum* on crops under protected environment (ZDAMU–Insect Collections, Department of Zoology, Aligarh Muslim University, Aligarh)

Comments: Encarsia formosa Gahan is cosmopolitan in distribution, and is being recorded for the first time from India. *E. formosa* was first described from the specimens reared from an unidentified aleyrodid on geranium in 1924 in a greenhouse in Idaho, United States (Gahan, 1924). It parasitizes at least 15 hosts in eight aleyrodid genera (Hoddle *et al.*, 1998). Around eighty species under the genus *Encarsia* Förster, 1878 are known from India (Hayat, 1998; Hayat, 2011; Poorani *et al.*, 2015; Noyes, 2016) except *E. formosa*. Earlier, fifty five natural enemies comprising predators (24), parasitoids (21) and pathogens (10) have been recorded associated with *T. vaporariorum* from different parts of the globe (CABI, 2016). In India, eight natural enemies constituting three parasitoids [*Encarsia inaron* (Walker), *E. sophia* (Girault and Dodd) and *Eretmocerus* sp.], three coccinellids [*Coccinella septempunctata* Linn., *Serangium haleemae* Afroze and Haider and *S. montazerii* Fürsch], a chrysopid [*Chrysoperla carnea* (Stephens)] and a predatory mite [*Amblyseius* (*Euseius*) *delhiensis* (Narayanan & Kaur)] have been found associated with greenhouse whitefly (Afroze and Haider, 1999; Kumar and Gupta, 2006; Chauhan *et al.*, 2007; Reecha, 2010).

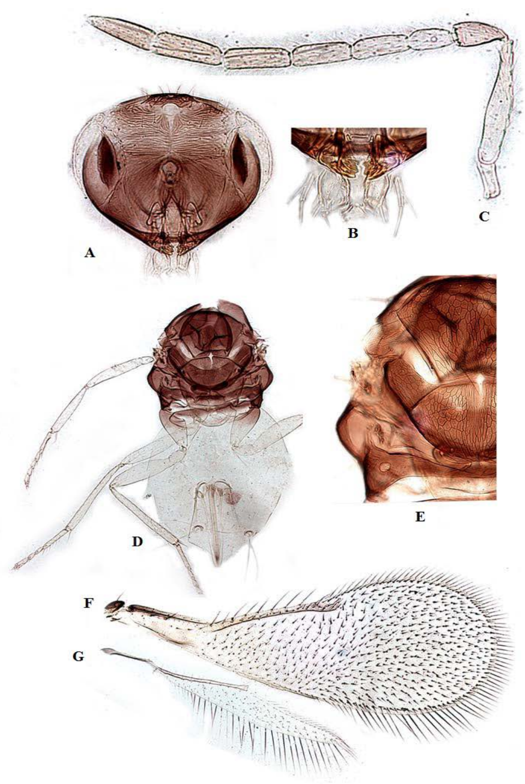

Fig. 2. A-G. *Encarsia formosa* Gahan, female. A. Head, frontal view; B. Mandibles and palps; C. Antenna; D. Mesosoma and metasoma, with legs of left side; E. Part of mesosoma showing sculpture and setation; F. Fore wing; G. Hind wing.

Dynamics of *Encarsia formosa* on Tomato

During 2015, parasitization by *E. formosa* varied from 3.92 to 25.46 and 19.32 to 81.21 per cent in different modules evaluated on 90 and 120 DAT, respectively with the corresponding parasitization of 31.78 and 93.33 per cent in Untreated Check (UC) (Table 1). In UC, significantly higher parasitization was recorded as compared to insecticidal modules. Parasitization was significantly higher in M_4 (soil application of imidacloprid 1 DAT followed by foliar application of azadirachtin started at 45 DAT at 10 days interval) as compared to other modules. It was followed by M_2 (soil applications of imidacloprid 1 DAT and 45 DAT). Whereas, the module comprising soil application of imidacloprid 1 DAT followed by alternate foliar applications of spiromesifen and thiamethoxam starting 45 DAT (M_7) resulted in significantly lowest parasitization. Whereas, during 2016, four efficacious modules namely, M_2, M_4, M_7 and M_8 were selected and evaluated. A perusal of data presented in Table 2 revealed that the activity of *E. formosa* was first recorded 82 DAT in UC with the corresponding parasitization of 36.76 per cent. On 89 DAT, parasitization was also evident in M_2 and M_4. The module M_7 remained free of greenhouse whitefly throughout the cropping season and was not included for statistical analysis. Based on mean parasitization observed on different dates of observations, it was observed that significant increase was evident from 96 to 124 DAT, with the maximum parasitization occurring in UC. Amongst the selected modules, M_4 (Soil application of imidacloprid followed by foliar application of azadirachtin starting at 45 DAT at 10 days interval) resulted in significantly higher parasitization followed by M_2 and M_8, which were on a par to each other.

Based on the outcome of two cropping seasons, it was evident that the activity of *E. formosa* was evident in later part of the crop growth (80-90 DAT) and untreated check resulting in significantly higher parasitization as compared to greenhouse whitefly management modules. Amongst different modes, the modules comprising soil application of imidacloprid followed by foliar application of azadirachtin proved relatively safe for the buildup of *E. formosa*.

Neonicotinoids are conventionally thought to be nonlethal to beneficial insects when applied as soil treatment instead of direct foliar sprays (Ruberson *et al.*, 1998; Krischik *et al.*, 2007) unless they feed on plant tissue or excretions or are exposed to the pesticide via food chain toxicity (Prabhaker, *et al.* 2011). However, Koppert (2016) on the compatibility of insecticides and biological control organisms revealed that toxicity of imidacloprid (both spray and soil drench) and thiamethoxam (spray) to *E. formosa* persists for a period of around 12 weeks after application. In present investigations it has been observed that activity of *E. formosa* starts after 12 weeks (of treatment and transplanting) and skips the persistent period of imidacloprid toxicity, if any.

Table 1. Parasitization of *Trialeurodes vaporariorum* by *Encarsia formosa* in different management modules in summer crop during 2015

Insecticide based module		Parasitization (%) on indicated days after transplanting (DAT)		
		90	120	Mean
M_1	Soil application of imidacloprid (0.009%) 1 DAT	13.02 (21.13)	73.95 (60.18)	43.48 (40.66)
M_2	Soil application of imidacloprid (0.009%) 1 DAT and 45 DAT	9.78 (18.22)	82.04 (65.81)	45.91 (42.01)
M_3	Foliar application of azadirachtin (0.00045%) at 10 days interval starting with10 DAT	8.75 (17.14)	47.06 (43.27)	27.90 (30.20)
M_4	Soil application of imidacloprid (0.009%) + foliar application of azadirachtin (0.00045%) starting at 45 DAT at 10 days interval	25.46 (30.24)	81.21 (64.69)	53.34 (47.47)
M_5	Alternate foliar applications of spiromesifen (0.02%) and thiamethoxam (0.01%) at 15 days interval starting 15 DAT	7.69 (16.01)	69.54 (56.62)	38.62 (36.31)
M_6	Alternate foliar applications of spiromesifen (0.02%) and thiamethoxam (0.01%) at 15 days interval when population goes beyond 5 adults/leaf	10.18 (18.54)	35.90 (36.76)	23.04 (27.65)
M_7	Soil application of imidacloprid (0.009%) 1 DAT + alternate foliar applications of spiromesifen(0.02%) and thiamethoxam (0.01%) starting 45 DAT	3.92 (11.37)	19.32 (26.04)	11.62 (18.70)
M_8	Soil application of imidacloprid (0.009%) 1 DAT + alternate foliar applications of spiromesifen(0.02%) and thiamethoxam (0.01%) starting 45 DAT when population goes beyond 5 adults/leaf	13.58 (21.59)	61.76 (51.78)	37.67 (36.69)
UC	Untreated check	31.78 (34.26)	93.33 (76.13)	62.56 (55.20)
	Mean	13.80 (20.94)	62.68 (53.48)	

Figures in parenthesis are the arcsine transformed values CD (P = 0.05)

Days after transplanting (A) :2.74

Module (B) :5.82

A × B :8.22

Table 2. Parasitization of *Trialeurodes vaporariorum* by *Encarsia formosa* in selective management modules in summer crop during 2016

Insecticide module		Parasitization (%) on indicated days after transplanting (DAT)								
		75	82	89	96	103	110	117	124	Mean
M_2	Soil applications of imidacloprid (0.009%) 1 DAT and 45 DAT	*	*	12.50	10.62 (3.41)	25.83 (4.89)	37.01 (6.17)	40.64 (6.45)	64.08 (8.07)	35.64 (5.80)
M_4	Soil application of imidacloprid (0.009%) + foliar application of azadirachtin (0.00045%) starting at 45 DAT at 10 days interval	*	*	30.00	37.65 (1.00)	35.00 (5.57)	36.12 (6.72)	36.12 (7.11)	49.98 (7.11)	38.97 (6.31)
M_7	Soil application of imidacloprid (0.009%) 1 DAT + alternate foliar applications of spiromesifen(0.02%) and thiamethoxam (0.01%) starting 45 DAT	*	*	*	*	*	*	*	*	*
M_8	Soil application of imidacloprid (0.009%) 1 DAT + alternate foliar applications of spiromesifen(0.02%) and thiamethoxam (0.01%) starting 45 DAT when population goes beyond 5 adults/ leaf	*	*	*	0.00 (6.22)	30.00 (6.00)	44.15(6.09)	49.50 (6.09)	49.50 (7.14)	34.63 (5.50)
UC	Untreated check	0.00	36.76	39.97	73.15 (8.61)	76.66 (8.81)	89.02 (9.49)	92.86 (9.68)	93.58 (9.73)	85.05 (9.26)
					30.36 (4.81)	41.87 (6.31)	51.58 (7.12)	54.78 (7.33)	64.29 (8.01)	

* No whitefly incidence occurred and not included in statistical analysis

Figures in parenthesis are the arcsine transformed values CD (P=0.05)

Days after transplanting (A) : 0.42

Module (B) : 0.38

A×B : 0.85

Present findings, the neem based module to result in significantly high parasitization draws support from the observations recorded by Feldhege and Schmutterer (1993) who also found azadirachtin (Margosan-O) to be selective for *E. formosa*. Simmonds (2002) observed a significant mortality of whitefly nymphs with no adverse effect on *E. formosa* emerging from them. Also Yankoval *et al.* (2011) observed neem based product BioNeem Plus 1.5 EC (azadirachtin) to be non-toxic to *E. formosa*.

Spiromesifen is generally classified as non-lethal to many natural enemies and was also proved harmless to the emergence of *E. smithi* from tea spiny whitefly *Aleurocanthus camelliae* (Ozawa and Uchiyama, 2014). Koppert (2016) also has classified spiromesifen as harmless or slightly harmful to *E. formosa* adults with no persistent toxicity. But in present investigations use of spiromesifen alongwith thiamethoxam (which is generally categorized as very harmful) might be the reason for lower activity of the parasitoid in related modules.

Encarsia formosa is a potential candidate to be exposed for inclusion in greenhouse whitefly management programme under protected cultivation. Also the safety of insecticides/ biopesticides needs to be determined for evolving a compatible plan.

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