Journal of Pest Science (2019) 92:1343–1357
https://doi.org/10.1007/s10340-018-01078-1

ORIGINAL PAPER

A re-examination of *Tuta absoluta* parasitoids in South America for optimized biological control

Nadia G. Salas Gervassio[1,2] · Daniel Aquino[1,3] · Consuelo Vallina[1] · Antonio Biondi[4] · María G. Luna[1,2]

Received: 29 October 2018 / Revised: 18 December 2018 / Accepted: 20 December 2018 / Published online: 31 January 2019

Abstract

We conducted a review of published information on *Tuta absoluta* parasitoids for the Neotropical region to (1) corroborate species records, (2) analyze associations including the *T. absoluta*, other insect and plant hosts and (3) identify research directions for enhancing their use as biological control agents. The literature review shows more than 50 species or morphospecies of Hymenoptera associated with *T. absoluta*, but less than a half (23) could be confirmed as parasitizing *T. absoluta*. Erroneous reports or invalid names of species, two new species records were found. Over a 100 pests and non-economically important insect and cultivated and non-cultivated plants directly or indirectly interact with *T. absoluta* in the region. Four *T. absoluta* parasitoid species include in their host range predatory insects or act as hyperparasitoids, a negative feature considered for a biological control agent. Five larval parasitoids have a narrow host range and could be considered for classical biological control programs in the areas of new invasion. Six Trichogrammatidae species are commercially used in various countries; of those, *T. minutum* and *T. pretiosum* are considered to be moderately generalist, being able to exploit several insect hosts. Apart from *Apanteles gelechiidivoris* and *Pseudapanteles dignus*, other native species have been the subject of field studies as biological control agents. The review presented here provides useful insights for identifying species that deserve further evaluation as *T. absoluta* biological control agents through augmentative or conservation strategies in South America, as well as for potential classical biological control programs in other continents.

Keywords Taxonomy · Parasitoid ecology · South American tomato pinworm · Host range · Food webs

Key message

- We provide a review of published records on *Tuta absoluta* parasitoids of the Neotropics.
- From more than 50 parasitoid species or morphospecies reported, only 23 hymenopteran species were confirmed as *T. absoluta* natural enemies.
- Other insect hosts, their host plants and the current knowledge on their potential as biological control agents were tracked.
- The low number of available parasitoids and those that have not yet been identified suggest that much work remains for optimizing the existing biological control services provided by *T. absoluta* parasitoids.

Communicated by M. Traugott.

SPECIAL ISSUE 2019: The South American tomato pinworm *Tuta absoluta*: recent advances in management methods against the background of an ongoing worldwide invasion.

✉ María G. Luna
lunam@cepave.edu.ar

[1] Centro de Estudios Parasitológicos y de Vectores (CEPAVE, CONICET-UNLP, Asociado CIC-BA), Boulevard 120 entre 60 y 64, 1900 La Plata, Argentina

[2] Departamento de Ciencias Exactas y Naturales, Universidad Nacional de San Antonio de Areco- UNSAdA, San Antonio de Areco, Argentina

[3] División Entomología, Museo de La Plata (FCNyM, UNLP), La Plata, Argentina

[4] Department of Agriculture, Food and Environment, University of Catania, Catania, Italy

Introduction

Parasitoids, as biological control agents, often exert strong host density reduction leading to suppression of pest densities and their economic damage (Debach and Rosen 1991; Hawikins and Cornell 2000). When compared to other biological control agents (i.e., predators and entomopathogenic organisms), insect parasitoids commonly show greater host search efficiency and host specificity, traits that are considered important in preventing nontarget host attacks. A number of parasitic insects have been imported from their native distribution regions and released in classical biological control programs against introduced invasive pests worldwide (e.g., Daane et al. 2016; Hardwick et al. 2016; Kenis et al. 2017; Tena et al. 2017; Cascone et al. 2018; Thancharoen et al. 2018). Approximately half of the commercially available biological control species belong to this entomophagous group (> 120 species), being mass-reared and released to control pests in horticultural crops (Zappalà et al. 2012; van Lenteren 2012; van Lenteren et al. 2018; Rossi Stacconi et al. 2018).

The Neotropical region is rich in native Hymenoptera species (Hanson and Gauld 1995); however, the magnitude of this diversity, as well as its history, biology and systematics, is poorly described (Fernández and Sharkey 2006). Yet, knowledge has been gained on several aspects of Neotropical parasitoids, and this provides the basis to develop effective biological control programs (several catalogues by De Santis; Parra et al. 2002; Parra and Zucchi 2004).

The South American tomato leaf miner *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is a key pest of tomato, native to this continent (Luna et al. 2015). During the last 12 years, *T. absoluta* was accidentally introduced to the Mediterranean Basin and dispersed throughout African and Eurasian continents (Desneux et al. 2011; Sankarganesh et al. 2017; Sylla et al. 2017; Mansour et al. 2018; Santana et al. 2019). Currently, this pest is threatening the tomato worldwide in many of its invaded regions (Campos et al. 2017; Biondi et al. 2018) and is considered to be a quarantine pest for the Australian (Plant Health Australia 2015) and North American (Bloem and Spaltenstein 2011) continents and for China, where approximately the 30% of the worlds tomato production occurs (Xian et al. 2017; Han et al. 2018). The crop damage is caused when the larvae that mine leaves and fruits, reducing tomato production and commercial value. This microlepidopteran species can inflicte up to 90% of crop losses when pest control measures fail (Desneux et al. 2011).

In South America, farmers have dealt with this pest for since the 1960s and chemical control is still the most widely employed tool (Guedes and Picanço 2012; Biondi et al. 2018). This can cause negative side effects, such as pest resistance, environmental contamination and the disruption of natural biological control (Siqueira et al. 2000; Lietti et al. 2005; Desneux et al. 2007; Biondi et al. 2012, 2013a; Passos et al. 2018; Roditakis et al. 2018). Consequently, biological control and other non-chemical pest management techniques have recently gained importance. Attempts to control *T. absoluta* in its native region include the use of selective insecticides, pheromone traps, insect sterile technique and biological control by means of pathogenic and entomophagous species (Bueno et al. 2013; Cagnotti et al. 2012; Consoli et al. 1998; Luna et al. 2015; Silva et al. 2015, 2016; van Lenteren et al. 2016; Soares et al. 2019). In this context, *T. absoluta* biological control using insect parasitoids was considered to be a potential control tool, resulting in scientific and technological research mostly in some South American countries, such as Argentina, Brazil, Chile, Colombia and Peru. Existing literature shows records of species used in classical biological control programs involving importation, mass rearing and releasing of Trichogrammatidae wasps in tomato fields among South American countries (Han et al. 2019). In practice, few native parasitoid species have been targeted for detailed studies, to determine their effectiveness as biological control agents in this region (Desneux et al. 2010; Biondi et al. 2018).

Thus, this review is intended to summarize the existing information on *T. absoluta* parasitoid complex in South America in literature and databases, with the following goals: (1) to corroborate parasitoid species records from original papers and their taxonomic status; (2) to analyze their ecological interactions with *T. absoluta*, other insect hosts and plant hosts; and (3) to identify research directions for promoting their use as biological control agents by means of augmentative, conservative or classical biological control approaches.

Data collection

We generated a list of *T. absoluta* parasitoids searching in Google Scholar using the keywords "*Tuta absoluta*" and its synonyms; all parasitoid specific names reported for *T. absoluta* and their synonyms; and common names in Portuguese and Spanish for *T. absoluta* (e.g., "traça do tomateiro," "polilla del tomate," "cogollero del tomate," etc.). We selected information published in primary literature sources, non-peer reviewed papers (technical reports, etc.), as well as review papers that summarized the *T. absoluta* natural enemies complex in the Neotropical region (e.g., Desneux et al. 2010; Biondi et al. 2018). The online Taxapad (Yu et al. 2012) and Universal Chalcidoidea Database (Noyes 2018) databases as well as specific papers and catalogs were accessed to confirm the species-level status and to search for other relevant taxonomic and ecological information. Only records at the specific level were considered. Morphospecies defined at family or genus levels were excluded because of the difficulty of tracking their hosts (insects or plants), as well as other biological or ecological traits of importance for pest control. Both native and introduced parasitoid species to South America were taken into account. In few cases, we discarded from the analysis those uncertain species records that lacked solid supporting bibliography confirming their association with *T. absoluta*. Species-specific categories on their insect and plant host specificity levels as well as their potential economic importance were generated.

Results

Twenty-three of ≈ 50 hymenopteran species or morphospecies cited in the literature were confirmed as attacking *T. absoluta* (Table 1). Another 24 morphospecies recorded only at the genus level were excluded; these were: *Archytas* sp., *Elfia* sp. and a not specified fly (Diptera Tachinidae); *Conura* sp. and *Invreia* sp. (Hymenoptera: Chalcididae); *Arrhenophagus* sp. and *Copidosoma* sp. (Hymenoptera: Encyrtidae); *Chrysonotomyia* sp., *Horimenus* sp., *Elasmus* sp., *Sympiesis* sp., *Tetrastichus* sp. and *Zagrammosoma* sp. (Hymenoptera: Eulophidae); *Anastatus* sp. (Hymenoptera: Eupelmidae); *Trichogramma* sp. (Hymenoptera: Trichogrammatidae); *Agathis* sp., *Apanteles* sp., *Bracon* sp., *Chelonus* sp., *Earinus* sp. and *Orgilus* sp. (Hymenoptera: Braconidae); and *Diadegma* sp., *Pristomerus* sp. and *Temelucha* sp. (Hymenopetra: Ichneumonidae).

We found multiple citations for *Pseudapanteles dignus* (Muesebeck) and *Apanteles dignus* (Muesebeck), *Dineulophus phthorimaeae* De Santis and *Retisympiesis phthorimaea* (Blanchard) and *Neochrysocharis formosus* (Westwood), *Neochrysocharis formosa* (Westwood) and *Closterocerus formosus* (Westwood). Such species were synonymized being firstly mentioned the current valid names. In the case of *Apanteles gelechiidivoris* Marsh and *Dolichogenidea gelechiidivoris* (Marsh), although both names are commonly used as synonyms, in a worldwide checklist on Microgastrinae (Hymenoptera: Braconidae) that is about to be published, the valid name will be defined (Fernández-Triana pers. comm.). Associations of *T. absoluta* with *Copidosoma desantisi* Annecke and Mynhardt (Hymenoptera: Encyrtidae) in Chile, and *Trichogramma dendrolimi* Matsamura in Chile and *T. lopezandinense* Sarmiento (Hymenoptera: Trichogrammatidae) in Colombia could not be found neither in the databases nor in the original papers where they were mentioned. *Trichogramma dendrolimi* was introduced in Brazil to control other insect pests than *T. absoluta* (Querino and Zucchi 2003). A similar situation occurred with *Trichogramma telengai* Sorokina that is cited for Chile; the species is a junior synonym of *T. bezdencovii* Bezdenko, and it is associated with *Rhyacionia buoliana* (Denis and Schiffmüller) in that country (Noyes 2018). The confirmed *T. absoluta* parasitoid species belong to the guilds of egg endoparasitoid, egg prepupal endoparasitoid, early larval endoparasitoid, larval ectoparasitoid, larval–prepupal endoparasitoid, prepupal–pupal ectoparasitoid and pupal endoparasitoid (Mills 1994). We also found two new records not listed previously (Desneux et al. 2010; Biondi et al. 2018): the pupal endoparasitoid *Conura bruchi* (Blanchard) (Hymenoptera: Chalcididae) (De Santis and Monetti 2008) and the egg endoparasitoid *Trichogrammatoidea brasiliensis* (Ashmead) (Hymenoptera: Trichogrammatidae) (De Santis 1989).

Tuta absoluta parasitoid diversity displayed a wide range of taxa among representing three superfamilies and nine families. Other insect and plant hosts comprise a complex of hundreds of species. Some species are generalists, for example, *N. formosus* with over 100 species of hosts in four different orders (Diptera, Coleoptera, Hymenoptera and Lepidoptera), whereas other species behave as more selective or specialists, being confined to insect hosts belonging to Gelechiidae (< 5 insect host species) and related to solanaceous plants. Examples of such species are: *Copidosoma gelechiae* Haward, *D. phthorimaeae*, *Goniozus nigrifemur* Ashmead, *A. gelechiidivoris*, *Bracon lucileae* Marsh and *P. dignus* (Table 1).

Thirteen species of the parasitoid complex are native to the Neotropics or to the American continent. Five species, mainly Trichogrammatidae, were intentionally introduced from other continents or moved among countries in that region as biological control agents against *T. absoluta* or other lepidopteran hosts (Table 1). Information related to the importation of many of these biological control agents in Latin America is often lacking or published in non-peer-reviewed articles. There are reports that mention *Trichogramma fasciatum* (Perkins), originally from Mexico, that was released in South America to control the sugar cane borer *Diatraea saccharalis* (Fabricius) (Lepidoptera: Pyralidae) (Burrell and McCormick 1962); *T. minutum* Riley was imported from North America to Chile and Peru for *T. absoluta* and *Heliothis zea* (Boddie) biological control (Lepidoptera: Noctuidae) (Klein Koch 1977); *T. pintoi* Voegele, originally from the Holarctic region, that was imported to South America for controlling several lepidopteran pests (Iannaconne and Lamas 2003; Querino and Zucchi 2003) and *Trichogrammatoidea bactrae* Nagaraja introduced from Australia to Argentina and Chile to mainly control the pink bollworm, *Pectinophora gossypiella* Saunders (Lepidoptera: Gelechiidae) (Hutchison et al. 1989; Riquelme Virgala and Botto 2010). The egg prepupal parasitoid *C. gelechiae* was imported from Australia to Peru as a natural enemy of *Phthorimaea operculella* (Zeller) (De Santis 1979). For

Table 1 List of confirmed parasitoid species attacking *Tuta absoluta* (Lepidoptera: Gelechiidae) in South America

Superfamily/family	Species	Mode of parasitism[a]	Other insect hosts[b]	Plant hosts (including tomato)[c]	Countries	Native/imported	Economic significance[d]	References
Chalcidoidea								
Aphelinidae	*Encarsia porteri* (Mercet)	Egg endoparasitoid	**3**	**3**	Argentina, Brazil, Chile, Ecuador, Peru	N	*2*	Cáceres et al. (2011), Luft et al. (2015) and Noyes (2018)
Chalcididae	*Conura bruchi* (Blanchard)	Pupal endoparasitoid (also as hyperparasite)	**3**	No reports	Argentina, Brazil	N?	1	De Santis (1967), Herting (1976), Noyes (2018) and De Santis and Monetti (2008)
Encyrtidae	*Copidosoma gelechiae* Howard	Egg prepupal	1	**3**	Peru	I	**4**	Peck (1963), De Santis (1979), Gordh (1979) and Noyes (2018)
	Copidosoma koehleri Blanchard	Egg prepupal (also as hyperparasite)	**3**	**3**	Argentina, Bolivia, Brazil, Chile, Peru, Uruguay, Venezuela	N?	**4**	Doutt (1948), De Santis (1967, 1979), Herting (1975) and Noyes and Hayat (1994)
Eulophidae	*Dineulophus phthorimaeae* De Santis	Larval ectoparasitoid	1	1	Argentina, Chile, Peru, Uruguay	N	1	Vargas (1970), De Santis (1983, 1989), Botto (1999) and Colomo et al. (2002)
	Neochrysocharis formosus (Westwood)	Larval–prepupal (also as hyperparasite)	**3**	**3**	Argentina	I?	**4**	Noyes (2018)
Pteromalidae	*Dibrachys microgastri* (Bouché)	Prepupal–pupal ectoparasitoid (also as hyperparasite)	**3**	**3**	Chile, Peru	I?	*2*	De Santis (1983) and Peters and Baur (2011)
Trichogrammatidae	*Trichogramma exiguum* Pinto & Platner	Egg endoparasitoid	*2*	*2*	Chile, Colombia, Peru, Uruguay	N	**4**	Desneux et al. (2010), Querino and Zucchi (2003) and IDMA—Instituto de Desarrollo y Medio Ambiente Perú (2018)
	Trichogramma fasciatum (Perkins)	Egg endoparasitoid	*2*	*2*	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Peru, Venezuela	I	**4**	De Santis (1979) and Colomo et al. (2002)
	Trichogramma minutum Riley	Egg endoparasitoid (also as hyperparasite)	**3**	**3**	Argentina, Bolivia, Brazil, Chile, Colombia, Guyana, Peru, Uruguay, Venezuela	I	**4**	Desneux et al. (2010)

Table 1 (continued)

Superfamily/family	Species	Mode of parasitism[a]	Other insect hosts[b]	Plant hosts (including tomato)[c]	Countries	Native/imported	Economic significance[d]	References
	Trichogramma nerudai Pintureau & Gerding	Egg endoparasitoid	*2*	*2*	Argentina, Chile	N	**4**	Cáceres et al. (2011) and Riquelme Virgala and Botto (2010)
	Trichogramma pintoi Voegele	Egg endoparasitoid	*2*	**3**	Argentina, Brazil[e], Peru	I	**4**	Desneux et al. (2010)
	Trichogramma pretiosum Riley	Egg endoparasitoid	**3**	**3**	Argentina, Brazil, Chile, Colombia, Ecuador, Peru, Uruguay, Venezuela	N	**4**	Vargas (1970), Miranda et al. (1998), Colomo et al. (2002), Parra and Zucchi (2004), Cáceres et al. (2011), Querino and Zucchi (2011) and Luft et al. (2015)
	Trichogramma rojasi Nagaraja & Nagarkatti	Egg endoparasitoid	**3**	*2*	Argentina, Brazil, Chile, Peru	N	*2*	Colomo et al. (2002), Cáceres et al. (2011), Ghoneim (2014), Luft et al. (2015) and Botto (1999)
	Trichogrammatoidea bactrae Nagaraja	Egg endoparasitoid	**3**	*2*	Argentina	I	**4**	Riquelme Virgala and Botto (2010) and Cagnotti et al. (2018)
	Trichogrammatoidea brasiliensis (Ashmead)	Egg endoparasitoid	**3**	**3**	Brazil, Chile, Colombia, Peru	N	*2*	De Santis (1989) and Noyes (2018)
Chrysidoidea								
Bethylidae	*Goniozus nigrifemur* Ashmead	Larval ectoparasitoid	1	*2*	No reports	No reports	No reports	Vargas (1970), Uchoa-Fernandes and de Campos (1993), Miranda et al. (1998) and Ghoneim (2014)
Ichneumonoidea								
Braconidae	*Apanteles* (=*Dolichogenidea*) *gelechiidivoris* Marsh	Larval–prepupal endoparasitoid	1	1	Colombia, Chile, Peru	N	**3**	Oatman and Platner (1989), Bajonero et al. (2008), Bajonero (2017), Morales et al. (2014) and Yu et al. (2012)

Table 1 (continued)

Superfamily/family	Species	Mode of parasitism[a]	Other insect hosts[b]	Plant hosts (including tomato)[c]	Countries	Native/imported	Economic significance[d]	References
	Bracon lucileae Marsh	Early larval endoparasitoid	1	1	Argentina, Brazil, Colombia	N	1	Oatman and Platner (1989), Uchoa-Fernandes and Campos (1993), Berta and Colomo (2000), Colomo et al. (2002), Cáceres et al. (2011) and Yu et al. (2012)
	Bracon lulensis Berta & Colomo	Early larval endoparasitoid	1	1	Argentina	N	1	Berta and Colomo (2000) and Yu et al. (2012)
	Bracon tutus Berta & Colomo	Early larval endoparasitoid	1	1	Argentina	N	1	Berta and Colomo (2000) and Yu et al. (2012)
	Pseudapanteles (=*Apanteles*) *dignus* (Muesebeck)	Larval–prepupal endoparasitoid	1	1	Argentina, Mexico, Cuba, Puerto Rico, USA (California, Florida) Hawaii	N	**3**	Botto (1999), Colomo et al. (2002), Cáceres et al. (2011) and Salas Gervassio et al. (2016)
Ichneumonidae	*Campoplex haywardi* Blanchard	Larval–pupal endoparasitoid	*2*	*2*	Argentina, Brazil, Brazil–Uruguay	N	*2*	Colomo et al. (2002) and Desneux et al. (2010)

Bold is a visual aid to indicate higher level for a given insect host range/plant host range/economic significance category

[a]As defined by Mills (1994)

[b]Other insect hosts: 1—< 5 spp., all Gelechiidae; 2—Lepidoptera in general; 3—more than one insect orders

[c]Plant hosts: 1—one family; 2—> one family, cultivated; 3—several families, cultivated and non-cultivated

[d]Economic significance: 1—only recorded; 2—laboratory studies; 3—field assessment; 4—classical or augmentative biological control agent

[e]Not confirmed in Brazil (Zucchi and Querino 2004)

other five species, information on their origin and geographic distribution is confusing or not reliable (Table 1).

Among the reviewed species, ten can be considered of economic importance because they have been used or are currently commercialized as biological control agents of *T. absoluta* and other insect pests (Table 1): *C. gelechiae*, *Copidosoma koehleri* Blanchard, *N. formosus*, *Trichogramma exiguum* (Girault), *T. fasciatum*, *T. minutum*, *T. nerudai* Pintureau and Gerding, *T. pintoi*, *T. pretiosum* Riley, *T. bactrae*. Two species, *A. gelechiidivoris* and *P. dignus*, are under field evaluation in South American countries with promising results (Morales et al. 2013; Bajonero 2017; Salas Gervassio 2017; Salas Gervassio et al. in prep.).

A brief review on the current knowledge of the main insect and plant host associations per each of the 23 species registered as *T. absoluta* parasitoids for the Neotropical region is provided below.

Superfamily Chalcidoidea

Family Aphelinidae

Encarsia porteri (Mercet). It is the only *Encarsia* species for which the development of males in lepidopterous eggs has been reported. Among hosts species of *E. porteri*, there are whiteflies (Hemiptera: Aleyrodidae) of the genus *Aleurocanthus*, *Aleurothrixus*, *Trialeurodes vaporariorum* (Westwood). It was reported attacking *T. absoluta* eggs in Argentina (Luft et al. 2015). It also parasitizes other lepidopterans of economic importance such as *Sitotroga cerealella* (Olivier) (Gelechiidae); *Anticarsia gemmatalis* Hubner, *Helicoverpa gelotopoeon* (Dyar), *H. zea*, *Rachiplusia nu* (Guenée) (Noctuidae); *Colias lesbia* Fabricius (Pieridae), *D. saccharalis*, *Ephestia kuehniella* Zeller, *Galleria mellonella* (Linneus) (Pyralidae); *Cydia pomonella* L., *Epinotia aporema* Walsingham (Tortricidae); and *Plutella xylostella* (L.) (Yponomeutidae). Diverse plant hosts associates include important South American cultivated species: *Chamaesyce hirta* L. (Euphorbiaceae), *Glycine max* L., *Medicago sativa* L., *Phaseolus lunatus* L., *Phaseolus vulgaris* L. (Fabaceae), *Gossypium* sp. and *Hibiscus rosa-sinensis* L.(Malvaceae), *Zea mays* L. (Poaceae), and *Solanum lycopersicum* L. and *S. tuberosum* L. (Solanaceae) (Noyes 2018; Yu et al. 2012).

Family Chalcididae

Conura bruchi (Blanchard). It was recorded as a primary endoparasitoid of pupae of three lepidopteran species, *Coleophora haywardi* Pastrana (Coleophoridae), *Psilopygida crispula* (Dognin) (Saturniidae) (De Santis 1967; Herting 1976), *T. absoluta* (Gelechiidae) and also from *Nematus desantisi* Smith (Hymenoptera: Tenthredinidae) (De Santis and Monetti 2008). It has been also recorded as a hyperparasitoid of *Apanteles crispulae* Blanchard (Hymenoptera: Braconidae) (De Santis 1967). Information on the biology, distribution and other associated species is lacking (Blanchard 1943).

Family Encyrtidae

Copidosoma gelechiae Howard. This species was imported from Australia to Peru in 1949 as a biological control agent against *Phthorimaea operculella* (Zeller), but releases were not continued. There exists only one record for South America as a endoparasitoid of *T. absoluta* in Peru (De Santis 1979). Other lepidopteran host species are the gelechiids *Gnorimoschema gallaeasteriella* (Kellicott), *G. gallaesolidaginis* (Riley) and *G. salinaris* Busck and the tortricid *Epiblema scudderiana* (Clemens) (Gordh 1979; Peck 1963). As plant associates, *C. gelechiae* was found, apart from solanaceous species, in *Solidago canadensis* L. (Asteraceae) (Rothman and Darling 1990).

Copidosoma koehleri Blanchard. Its distribution covers Argentina (Blanchard 1940), Bolivia (Noyes and Hayat 1994), Brasil (Herting 1975), Chile (Herting 1975; Doutt 1948), Venezuela (Ferrer 2001; Noyes 2018), Peru and Uruguay (De Santis 1979; Herting 1975). The species was found parasitizing different species of Gelechiidae (Lepidoptera), such as *T. absoluta* (De Santis 1979), *P. operculella* (De Santis 1979; Ferrer 2001) and *Symmetrischema tangolias* (Gyen); and the Tortricidae *Grapholita molesta* (Busck) (De Santis 1967; Guerrieri and Noyes 2005). Laboratory studies of interspecific competition with the two parasitoids *Apanteles subandinus* Blanchard and *Chelonus blackburni* Cameron (Hymenoptera: Braconidae) showed inconclusive results on *C. koehleri* ability to outcompete other *P. operculella* biological control agents (Whiteside 1981; Ballal et al. 1989). Moreover, it was proved that it is a hyperparasitoid of *Diglyphus isaea* Walker (Hymenoptera: Eulophidae) (Ozawa et al. 2002). As plant hosts, *C. koelheri* can be found in: *Schinus molle* L. (Anacardiaceae), *Borago officinalis* L. (Boraginaceae), *Azadirachta indica* A. Juss. (Meliaceae), *Fagopyrum esculentum* Moench. (Polygonaceae), *Capsicum annuum* L., *S. lycopersicum*, *Nicotiana* sp., *Solanum chacoense* Bitter., *Solanum pinnatisectum* Dunal., *Solanum polytrichon* Rydb., *S. tuberosum* (Solanaceae), *Lantana camara* L. (Verbenaceae). *Copidosoma koehleri* was introduced and released in California in 1964 to control *P. operculella* but apparently, it failed to establish (Noyes 1988).

Family Eulophidae

Dineulophus phthorimaeae De Santis. It was De Santis 1983) and Peru (De Santis and Fidalgo 1994) as an ectoparasitoid of *Gnorimoschema operculella* and *T. absoluta* (Lepidoptera: Gelechiidae) (De Santis 1983, 1989; De Santis and

Monetti 2008) infesting *S. lycopersicum* and *S. tuberosum* (Berta de Fernandez and Colomo de Correa 1991; De Santis 1983). The species description was carried out by De Santis in 1983, using material labeled by Blanchard as *Rhetisympiesis phthorimaeae*, collected by Lopez Mansilla in 1939. *R. phthorimaeae* is not considered a valid name because Blanchard never described the species beyond having named it. Laboratory and field research done on this ectoparasitoid species by Savino et al. (2012, 2016) showed that it has an extremely sinovigenic reproductive strategy and it practices non-reproductive host feeding, a parasitoid mechanism that causes a significant host mortality. When competing with the larval endoparasitoid *P. dignus*, younger *D. phthorimaeae* females avoided multiparasitism, but older females did not discriminate heterospecific parasitized larvae. This eulophid is a potentially effective biological control agent for *T. absoluta*, and it could be used through augmentative as well as conservative biological control strategies in IPM programs. Furthermore, when acting together with *P. dignus* in tomato crops, they can exert an important control of this pest (up to 80% of host larvae mortality).

Neochrysocharis formosus (Westwood). Formerly named as *Closterocerus formosus* and often wrongly cited as *N. formosa*, it was reported for Argentina and Mexico (Luna et al. 2011; Hansson 1997). It is a polyphagous species known to attack a wide variety of leaf miners and gall-forming insects. As stated above, it has been recorded as a primary parasitoid from over 100 species of hosts in five different orders of insects, and also as a hyperparasitoid of *D. isaea*. It is present in cultivated and non-cultivated plant species, and in total, it has been recorded from more than 60 different plant species in 26 families: Apiaceae, Aquifoliaceae, Asclepiadaceae, Asteraceae, Brassicaceae, Caryophyllaceae, Chenopodiaceae, Cucurbitaceae, Cupressaceae, Euphorbiaceae, Fabaceae, Fagaceae, Liliaceae, Oleaceae, Pinaceae, Poaceae, Portulaceae, Ranunculaceae, Resedaceae, Rosaceae, Rubiaceae, Rutaceae, Salicaceae, Solanaceae, Tamaricaceae, Urticaceae (Thompson 1955; Noyes 2018; Luna et al. 2011). Recently, it was found parasitizing *T. absoluta* in Europe (Zappalà et al. 2012; Biondi et al. 2013b).

Family Pteromalidae

Dibrachys microgastri (Bouché). It is a cosmopolitan species (De Santis 1983; Peters and Baur 2011) listed for 57 countries (Noyes 2018). As a primary parasite or hyperparasite, this species is associated mainly with insects belonging to eight insect orders: Coleoptera, Dermaptera, Diptera, Hemiptera, Hymenoptera (including hyperparasites), Lepidoptera, Neuroptera and Sterpsiptera, and also with spiders (Peters and Baur 2011; Dzhanokmen 2017). It was recorded as parasitizing the prepupal and pupal stages of *T. absoluta* in Chile and Peru (De Santis 1983). In Argentina, it was found hyperparasitizing *Mastrus ridens* Horstmann (Braconidae) and *Ascogaster quadridentata* Wesmael (Ichneumonidae) (D'Hervé and Aquino 2016).

Family Trichogrammatidae

Trichogramma exiguum Pinto and Platner. It is a Neotropical species, mass-reared and released in Colombia and Peru (Noyes 2018; Desneux et al. 2010; IDMA—Instituto de Desarrollo y Medio Ambiente Perú 2018). Its primary hosts are eggs of the following lepidopteran species: *Erinnyis ello* (L.) (Sphingidae), *Alabama argillacea* (Meyrick), *H. zea*, *Heliothis virescens* (Fabricius) and *Sacadodes pyralis* Dyar (Noctuidae), *Dione juno juno* (Cramer) (Nymphalidae), *D. saccharalis*, *Neoleucinodes elegantalis* (Guenée) and *Palpita persimilis* Walker (Crambidae), *Dichomeris* sp. and *S. cerealella*, *T. absoluta* (Gelechiidae), *Pococera atramentalis* Lederer (Pyralidae), *Argyrotaenia sphaleropa* (Meyrick) and *Bonagota cranaodes* (Meyrick) (Tortricidae). Host plants are important crops for South America: cassava, several *Citrus* sp., cotton, sugarcane, corn, sorghum, passion fruit and olive orchards (Querino and Zucchi 2003).

Trichogramma fasciatum (Perkins). Although it was introduced for biological control of insect pest species on crops other than tomatoes, it was found naturally parasitizing *T. absoluta* eggs. Other insect hosts comprise the lepidopteran species *E. ello*, *Oxydia trychiata* Guenée (Geometridae), *Acleris gloveranus* (Walsingham), *Corcyra cephalonica* (Stainton), *C. pomonella*, several *Diatraea* sp., *Maruca vitrata* (Fabricius), *Mescinia peruella* Schaus, *Procerata sacchariphaga* (Bojer), *Sitotroga* sp., and the noctuids *A. argillacea*, *Euproctis chrysorrhoea* (L.) (Noctuidae), several species of *Helicoverpa* and *Heliothis*, *Lymantria monacha* (L.), *Mamestra brassicae* (L.), *S. pyralis* and *Spodoptera frugiperda* (Smith) (De Santis 1979; Colomo et al. 2002; Noyes 2018). Associated plant hosts are cultivated species, as *Brassica oleracea* L., *Cedrela odorata* L. and *C. tonduzii* C.DC, cotton, sugarcane and corn (Yu et al. 2012).

Trichogramma minutum Riley. It is an extremely generalist species. It is widely commercialized as a biological control agent and introduced in South America. Insect host range includes pest species belonging to Hemiptera, as *Aleyrodes* sp., seven species of Coleoptera Chrysomeloidea and several Tenebrionoidea. Over 50 host species of Macrolepidoptera and more than 70 species of Microlepidoptera are reported. Dipteran hosts include Brachycera and Cyclorrapha species, Hymenoptera Symphyta and parasitic wasps, as other Trichogrammatidae and Braconidae. It is important to mention that *T. minutum* wasps can attack eggs of other beneficial entomophagous species, such as predatory species of orders Neuroptera and Coleoptera, the coccinelid ladybird *Coleomegilla maculata* (DeGeer), as well as parasitic wasps of Hymenoptera Braconidae and *Trichogramma japonicum*

Ashmead. Plant host associates are diverse, crop and non-crop species. The list comprises *Abies* sp., *Picea* sp. and *Pinus* sp., oak, birch and poplar trees; horticultural crops as beet, lettuce, cabbage, pumpkin, peas and beans; passion fruit, citrus, plum and apple orchards; extensive crops as soybean, cassava, cotton, rice, sugarcane, sorghum, trefoil, corn; and uncultivated species, as *Asclepias* sp., *Cyperus* sp., *Datura* sp., several Malvaceae and *Nicotiana* sp. (De Santis 1979; Noyes 2018; Yu et al. 2012).

Trichogramma nerudai Pintureau and Gerding. Native to Chile, it was introduced and released to Argentina (Querino and Zucchi 2003; Riquelme Virgala and Botto 2010) and associated with two species of Lepidoptera: *S. cerealella*, *T. absoluta* (Gelechiidae), *H. zea* (Noctuidae), *E. kuehniella* (Pyralidae), *C. pomonella*, *R. buoliana* (Tortricidae), *P. xylostella* (Yponomeutidae). Plants associated: *Pinus radiata* D. Don, *P. contorta* Douglas, *P. ponderosa* Douglas, *P. taeda* L. (Pinaceae); *Z. mays* (Poaceae), *Malus domestica* Borkh (Rosaceae), *S. lycopersicum* (Solanaceae), *Brassica oleracea* L. (Brassicaceae) (Pintureau et al. 1999; Querino and Zucchi 2003; Noyes 2018).

Trichogramma pintoi Voegele. It was introduced and massively reared as a biological control agent in Argentina and Peru for controlling *H. zea*, and the tortricids *Cydia leguminis* (Heinrich) and *C. pomonella* (Pinto 1999). Its spontaneous occurrence in Brazil could not be confirmed, and Querino and Zucchi (2004) speculate that it is probably a new species in this country. It has a wide host range among lepidopterans, comprising the species *Antheraea pernyi* Guerin-Meneville and *Samia cynthia* (Drury) (Saturniidae), *C. cephalonica* (Pyralidae), *Cydia nigricana* (Fabricius) (Tortricidae), *E. kuehniella*, *Lycaeides melissa* (Edwards) and *Plebejus acmon* (Westwood and Hewitson), (Lycaenidae), *Ostrinia nubilalis* (Hubner) (Crambidae), *Platyptilia carduidactyla* (Riley) (Pterophoridae), *P. xylostella*, *S. cerealella* and *Vanessa* sp. (Nymphalidae). Among noctuid hosts, there are *Agrotis segetum* (Denis and Schiffermuller), *H. armigera*, *Leucoma salicis* (L.), *M. brassicae* and *Ochropleura fennica* (Tauscher). As host plants, *T. pintoi* can be found in cultivated as cotton and *Salix* trees, and in uncultivated species or weeds, like *Baccharis*, *Chrysothamnus*, the black thistle, the wild buckwheat, the American licorice and *Malva* sp. (Noyes 2018).

Trichogramma pretiosum Riley. Mass-reared and released in Brazil, Chile, Colombia, Ecuador and Peru. It is a Neotropical species associated principally with: Curculionidae (Coleoptera); Anthocoridae and Lygaeidae (Hemiptera); Arctiidae, Blastobasidae, Danaidae, Gelechiidae, Geometridae, Hesperiidae, Lycaenidae, Lymantriidae, Noctuidae, Notodontidae, Nymphalidae, Oecophoridae, Papilionidae, Pieridae, Pyralidae, Sphingidae, Syntomidae, Tortricidae, Yponomeutidae (Lepidoptera); and Chrysopidae (Neuroptera) (Noyes 2018; Querino and Zucchi 2011).

Trichogramma rojasi Nagaraja and Nagarkatti. It is distributed in Argentina, Brazil, Chile, Cuba and Peru (Noyes 2018). Host species include Lepidoptera, Gelechiidae: *Anarsia gemmatalis*, *T. absoluta*; Hesperiidae: *Prenes ares* Felder; Noctuidae: *A. gemmatalis*, *Mocis latipes* Guenée, *Pseudaletia sequax* Franclemont, *R. nu*, *S. frugiperda*; Pieridae: *C. lesbia*, *Tatochila* sp.; and Pyralidae: *C. cephalonica*. Host plants are all cultivated and belong to the following families: Fabaceae: *G. max*, *M. sativa*, *P. vulgaris*, *Trifolium* sp and Poaceae: *Panicum maximum* Jacq, *Z. mays* (Nagaraja and Nagarkatti 1973; Zucchi and Monteiro 1997; Querino and Zucchi 2003; Noyes 2018).

Trichogrammatoidea bactrae Nagaraja. It is an exotic parasitoid introduced in Argentina in the 1990s, to be evaluated as biological control agent of *Pectinophora gossipiella* (Saunders) (Lepidoptera: Gelechiidae) in cotton and later of *T. absoluta* in tomato. Preliminary laboratory studies showed that this parasitoid is more efficient than *T. pretiosum* and *T. rojasi*, two local species, in parasitizing *T. absoluta* eggs (Botto 1999; Riquelme Virgala and Botto 2010). Inundative releasing experiments were done by Cagnotti et al. (2018). They evaluated dispersion and persistence of the wasp in tomato greenhouses with the aim of adjusting *T. bactrae* releasing points and pest control. It is associated with Anthomyiidae, Sciomyzidae (Diptera); Blastobasidae, Gelechiidae, Hesperidae, Oecophoridae, Pieridae, Pyralidae, Sphingidae, Tortricidae and Yponomeutidae (Lepidoptera). Host plants registered are members of the Araceae, Brassicaceae, Cyperaceae, Fabaceae, Malvaceae, Poaceae, Proteaceae and Solanaceae families (Noyes 2018).

Trichogrammatoidea brasiliensis (Ashmead). It is distributed in Brazil, Chile, Colombia and Peru (De Santis 1989; Noyes 2018). Among the insect host species, there are *T. absoluta*, *P. operculella*, *R. nu*, *E. aporema*, *S. cerealella*, *H. zeae* (Lepidoptera) and *Kerria lacca* Kerr (Hemiptera). Diverse plant hosts associates include families Asteraceae, Fabaceae, Malvaceae, Meliaceae, Poaceae and Solanaceae (Noyes 2018).

Superfamily Chrysidoidea

Family Bethylidae

Goniozus nigrifemur Ashmead. Besides *T. absoluta*, other host species include the pink bollworm *P. gossypiella*. However, further information on its biology, distribution and other associated species is still lacking. Few quantitative data are available on the biology and behavior of this species. It is a gregarious arrhenotokous ectoparasitoid, it prefers the third and fourth host larval stage and the pupa is protected by a silken cocoon (Vargas 1970; Luft 1993, 1996; Uchoa-Fernandes and de Campos 1993; Miranda et al. 1998). Brewer and Varas (1971) evaluated a massive-rearing protocol and releases of this parasitoid in Córdoba (Argentina) to control *P. gossypiella* and *R. buoliana*.

Superfamily Ichneumonoidea

Family Braconidae

Apanteles gelechiidivoris Marsh. Native to South America, namely Chile, Colombia and Peru, this species was introduced in California (Yu et al. 2012). As primary hosts, there are mentioned three gelechiid species: *T. absoluta* (Bajonero et al. 2008), *P. operculella* (Morales et al. 2014) and *Keiferia lycopersicella* (Walsingham) (Yu et al. 2012) infesting *S. lycopersicum* or *S. tuberosum* (Solanaceae) (Oatman and Platner 1989). It is considered the most important parasitoid for natural and augmentative biological control in Colombian tomato crops (García Roa 1989; Bajonero 2017).

Bracon lucilae Marsh. It is a Neotropical species. Insect primary hosts are larvae of the following lepidopteran species (Gelechiidae): *T. absoluta* (Uchoa-Fernandes and de Campos 1993; Colomo et al. 2002), *P. operculella* (Yu et al. 2012) and *Scrobipalpula isochlora* Meyrick (Oatman and Platner 1989). Associated plant hosts are solanaceous cultivated and non-cultivated species, such as *S. lycopersicum*, *S. tuberosum* and *S. saponaceum* Dunal (Oatman and Platner 1989).

Bracon lulensis Berta and Colomo and *Bracon tutus* Berta and Colomo. Both species were described as larval parasitoids of *T. absoluta* in northern Argentinian tomato crops (Berta and Colomo 2000). However, further information on the biology, distribution and other associated species is lacking.

Pseudapanteles dignus (Muesebeck). It is distributed in the New World, originally described by Muesebeck in 1938 as *Apanteles dignus*, and revised by Mason in 1981 (Yu et al. 2012; Fernández-Triana et al. 2014). It was imported to Hawaii for the biological control of *K. lycopersicella*, from 1975 to 1982, but no further information is available about its establishment (Nakao and Funasaki 1979; Nakao et al. 1981; Lai and Funasaki 1985). Other host records include the gelechiids *P. operculella*, *Tildenia gudmannella* Walsingham and *Symmetrischema capsica* (Bradley and Povolný) (Cardona and Oatman 1971; Fernández-Triana et al. 2014). The associated plants include members of the Solanaceae family, such as *S. lycopersicum*, *S. tuberosum*, *Capsicum annum* L., *Solanum sisymbriifolium* Lam., *S. americanum* Mill., *Nicotiana glauca* Graham (Cáceres et al. 2011; Salas Gervassio et al. 2016). Currently, experimental releases of this parasitoid to evaluating its efficiency as a biological control of *T. absoluta* in tomato greenhouse in Argentina are being carried out (Salas Gervassio 2017, Salas Gervassio et al. ms in prep.).

Family Ichneumonidae

Campoplex haywardi Blanchard. It is a Neotropical species. Other insect hosts known apart from *T. absoluta* are *P. operculella* (Gelechiidae) in *S. tuberosum* (potato) (Yu et al. 2012) and *Ithome* sp. (Lepidoptera: Walshiidae) in legume trees (Colomo et al. 2002). It has been imported in California to control *P. operculella* but apparently, it did not establish (Nechols et al. 1995).

Discussion

Regarding our first objective to corroborate the parasitoid species records from original papers and their taxonomic status, it is clear from this review that more than a half of the complex of *T. absoluta* parasitoids reported for South America, including Tachinids, needs further examination to confirm their species-level identifications, insect and plant resources used and more importantly, their impact on *T. absoluta* population. For instance, 24 of the records fell into the category of morphospecies, at genus level, from which little biological information can be collected. We also report two duplicated records, one erroneous record and four junior synonyms.

In relation to their ecological interactions with *T. absoluta*, other insect hosts and plant hosts, ca. eight species of the *T. absoluta* parasitoid complex showed to have a quite narrow insect or plant host ranges reported. However, the lack of records on other insect hosts may be due to a poor knowledge of their distribution or biological features rather than its absence (Luna et al. 2011). Nevertheless, the diversity and the abundance of guilds of native parasitoids species associated with *T. absoluta* show that many of them are able to coexist thanks to a complex food web that also include alternative insect hosts, as well as the vegetation supporting those herbivores (Mills 1994).

When comparing the South American parasitoid complex of *T. absoluta* in its native and invaded ranges of distribution, a strong pattern of adaptation to the new host can be observed, with 53 species forming new associations in about 12 years from the invasion start (Desneux et al. 2010; Zappalà et al. 2013; Biondi et al. 2018). It is interesting that only one cosmopolitan parasitoid species, *N. formosus*, was found in association with *T. absoluta* in both native and recently invaded areas. Since many of them have been registered at genus level, probably a similar study should be done to confirm the interactions among the species records with *T. absoluta* in invaded areas.

The interest for developing *T. absoluta* biological control programs in South American countries led to the indiscriminate introduction of several generalist parasitoid species that did not coevolved with *T. absoluta*. Classical and neoclassical biological control agents can have undesirable effects on nontarget hosts, being either other phytophagous or beneficial arthropods (Simberloff and Stiling 1996; Louda et al. 2003). This, for example, was the case for the generalist egg parasitoid *T. minutum*, imported from North America into Argentina, Bolivia, Brazil, Chile, Colombia, Guyana, Peru, Uruguay and Venezuela (Querino and Zucchi 2003; IDMA—Instituto de Desarrollo y Medio Ambiente Perú 2018). The species parasitizes eggs of predatory species of chrysopids and coccinelids, and it can act as a hyperparasitoid of braconids and other trichogrammatids (Yu et al. 2012). The introduction of this natural enemy in South America is a clear example of the need to conduct rigorous pre-importation studies when a classical biological control program is implemented. Multi-host field samplings in the native area (Daane et al. 2016), host range laboratory testing (Desneux et al. 2012; Girod et al. 2018), a careful analysis of the published literature data (van Lenteren and Manzaroli 1999; Charles 2012), as well as the correct taxonomic identification (Desneux et al. 2009; Beltrà et al. 2015; Guerrieri et al. 2016), are recommended in order to better assess the specificity of natural enemies as candidates for classical biological control programs of any invasive insect pest, in a perspective of specific risk–benefit analysis (Heimpel and Cock 2018). In particular, here we identified one eulophid (*D. phthorimaea*) and five braconid species (*A. gelechidiivoris*, *B. lucilae*, *B. lulensis*, *B. tutus* and *P. dignus*) with higher specificity (double category 1 in Table 1) that deserve greater attention for potential classical biological control programs of *T. absoluta* in the recently invaded areas, where the pest is causing considerable economic and environmental damage (Campos et al. 2017; Biondi et al. 2018). The species *C. bruchi*, *C. koehleri*, *D. microgastri* and *N. formosus* should be dismissed as biological control agents since they can act as hyperparasitoids (Yu et al. 2012; Noyes 2018).

Augmentative biological control for *T. absoluta* is commercially available in South America through the sale of the parasitoids *T. pretiosum* (in Brazil, Chile, Colombia, Ecuador and Peru), *T. nerudai* in Chile and *T. bactrae* in Chile and Peru. Besides, two other *Trichogramma* species, *T. exiguum* and *T. pintoi*, are mass-reared and commercialized by local companies in South America for controlling other lepidopteran pests). Finally, three further *Trichogramma* species (*T. galloi* Zucchi in Brazil, *T. cacoeciae* Marchal and *T. fuentesi* Torre in Peru) are marketed, but there are no records on their associations with *T. absoluta* (Noyes 2018; Yu et al. 2012). Therefore, a careful host and host-plant suitability assessment (Chailleux et al. 2012; 2013; Cascone et al. 2015; Thiery and Desneux 2018) is needed before potential inclusion of these *Trichogramma* species in biological or integrated *T. absoluta* control programmes.

Conservation biological control, often described as the field of biological control with the greatest potential for use in developing world agriculture (Wyckhuys et al. 2013), has received practically no attention in South America. As demonstrated in Salas Gervassio et al. (2016), *T. absoluta* trophic web, including interactions with dozens of parasitoid species, along with an unknown number of other entomophagous arthropods, inhabiting cultivated and wild solanaceous plants should be protected to help maintaining *T. absoluta* populations at low levels in horticultural farms. Much more efforts are thus needed in order to understand how functional biodiversity, at the landscape and farm levels, and to contribute increasing the ecological services provided by *T. absoluta* parasitoids (Holzschuh et al. 2010; Zappalà et al. 2012). This is particularly important for *T. absoluta* Neotropical parasitoids because we found over a hundred of alternative host insects, infesting cultivated and non-cultivated plants, that indirectly (via apparent competition) interact with *T. absoluta* in the region.

The results of this paper are intended to identify research directions for promoting the use of native biological control agents by means of augmentative or conservation tactics in the region. Overall, we conclude that the bibliography contains many unreliable *T. absoluta* parasitoid records. However, we identified several native parasitoid species, with a quite narrow insect host range (categories 1 or 2 in Table 1) from the complex of *T. absoluta* in South America, deserve more attention to be used in (1) conservative and augmentative biological control strategies in South America, and some of them (2) for being considered potential classical biological control programs in the newly invaded areas.

Author contribution statement

All authors conceived the research and performed the bibliographic research. NGSG, DA and MGL wrote the first manuscript draft. All authors interpreted the data and revised the first manuscript draft.

Acknowledgements We thank N. Mujica (CIP, Peru), M. R. Manzano (Universidad Nacional de Colombia Sede Palmira, Colombia), J. L. Fernández-Triana (Canadian National Collection of Insects, Ottawa, Canada) for providing information on the biology or economic importance of parasitoid species in South America. We gratefully acknowledge the financial support from PICT-2015 1427 and PICT-2016-8034 (FONCYT, MINCYT, Argentina), and PID N829 (UNLP, Argentina) and 5A722192113 (University of Catania, Italy). Authors are also grateful to anonymous referees and the editor for constructive comments on an earlier version of the manuscript.

Compliance with ethical standards

Conflict of interest The authors have declared that no conflict of interest exists.

Ethical approval All applicable international, national and/or institutional guidelines for the care and use of animals were followed. This article does not contain any studies with human participants performed by any of the authors.

References

Bajonero JG (2017) Release of *Apanteles gelechiidivoris* for biological control of *Tuta absoluta* in tomato greenhouse in Colombia. n15° Simposio de Controle Biológico, Ribeirao Preto

Bajonero JG, Códoba N, Cantor F, Rodríguez D, Curo JR (2008) Biology and life cicle of *Apanteles gelechiidivoris* (Hymenoptera: Braconidae) parasitoid of *Tuta absoluta* (Lepidoptera: Gelechiidae). Agron Colomb 26:417–426

Ballal CR, Singh SP, Jalali SK, Kumar P (1989) Parasitizing efficiency of *Chelonus blackburni* Cam. and *Copidosoma koehleri* Blanch. singly and in combination against the potato tuber moth. J Biol Control 3:4–6

Beltrà A, Addison P, Avalos JA, Crochard D, Garcia-Marí F et al (2015) Guiding classical biological control of an invasive mealybug using integrative taxonomy. PLoS ONE 10:e0128685

Berta CD, Colomo MV (2000) Dos especies nuevas de *Bracon* F. y primera cita para la Argentina de *Bracon lucileae* Marsh (Hymenoptera, Braconidae), parasitoides de *Tuta absoluta* (Meyrick) (Lepidoptera, Gelechiidae). Insecta Mundi 14(4):211–219

Berta de Fernandez CD, Colomo de Correa MV (1991) Presencia de *Dineulophus phthorimaeae* De Santis (Hymenoptera: Eulophidae) en Tucumán, ectoparásito de larvas de *Scrobipalpula absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Rev Soc Entomol Argent 49(1–4):156

Biondi A, Desneux N, Siscaro G, Zappalà L (2012) Using organic-certified rather than synthetic pesticides may not be safer for biological control agents: selectivity and side effects of 14 pesticides on the predator *Orius laevigatus*. Chemosphere 87:803–812

Biondi A, Zappalà L, Stark JD, Desneux N (2013a) Do biopesticides affect the demographic traits of a parasitoid wasp and its biological control services through sublethal effects? PLoS ONE 8(9):e76548

Biondi A, Chailleux A, Lambion J, Han P, Zappalà L, Desneux N (2013b) Indigenous natural enemies attacking *Tuta absoluta* (Lepidoptera: Gelechiidae) in Southern France. Egypt J Biol Pest Control 23:117–121

Biondi A, Guedes RNC, Wan FH, Desneux N (2018) Ecology, worldwide spread, and management of the invasive South American tomato pinworm, *Tuta absoluta*: past, present, and future. Annu Rev Entomol 63:239–258

Blanchard EE (1940) Apuntes sobre Encirtidos argentinos. An Soc Cient Argent 130:107

Blanchard EE (1943) Un díptero y seis himenópteros argentinos nuevos para la ciencia. Rev Soc Entomol Argent 12:92–104

Bloem S, Spaltenstein E (2011) New pest response guidelines. Tomato leafminer (*Tuta absoluta*). Guideline USDA-APHIS-CSDA. Emergency and Domestic Programs

Botto EN (1999) Control biológico de plagas hortícolas en ambientes protegidos. Rev Soc Entomol Argent 58:58–64

Brewer M, Varas D (1971) Cria masiva de *Parasierola nigrifemur* (Ash.), (Hym., Bethylidae): Primeras liberaciones en Calamuchita, Córdoba, Argentina. Rev Peru Entomol 14(2):352–361

Bueno VHP, van Lenteren JC, Lins JC, Calixto AM, Montes FC, Silva DB, Pérez M (2013) New records of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) predation by Brazilian Hemipteran predatory bugs. J Appl Entomol 137:29–34

Burrell W, McCormick WJ (1962) Effect of Trichogramma releases on parasitism of sugarcane borer eggs. J Econ Entomol 55(6):880–882

Cáceres S, Aguirre A, Miño V, Almonacid R (2011) Líneas de trabajo para el manejo integrado de la polilla del tomate en Corrientes. Libro de Resúmenes del Taller: La polilla del tomate en la Argentina: Estado actual del conocimiento y prospectiva para un manejo integrado de plagas. FCNyM, UNLP, p 7

Cagnotti CL, Viscarret M, Riquelme MB, López SN (2012) Effects of X-rays on *Tuta absoluta* for use in inherited sterility programmes. J Pest Sci 85:413–421

Cagnotti CL, Riquelme Virgala M, Botto EN, López SN (2018) Dispersion and Persistence of *Trichogrammatoidea bactrae* (Nagaraja) over *Tuta absoluta* (Meyrick), in Tomato Greenhouses. Neotrop Entomol 47:553–559

Campos MR, Biondi A, Adiga A, Guedes RNC, Desneux N (2017) From the Western Palaearctic region to beyond: *Tuta absoluta* ten years after invading Europe. J Pest Sci 90:787–796

Cardona C, Oatman R (1971) Biology of *Apanteles dignus* (Hymenoptera: Braconidae), a primary parasite of the tomato pinworm. Ann Entomol Soc Am 64:996–1007

Cascone P, Carpenito S, Slotsbo S, Iodice L, Sørensen JG, Holmstrup M, Guerrieri E (2015) Improving the efficiency of *Trichogramma achaeae* to control *Tuta absoluta*. Biocontrol 60:761–771

Cascone P, Carpenito S, Lodice L, Raimo S, Guerrieri E (2018) Introduction and acclimation of *Torymus sinensis* in the South of Italy. Emtomol Gen 37:93–101

Chailleux A, Desneux N, Seguret J, Khanh HDT, Maignet P, Tabone E (2012) Assessing European egg parasitoids as a mean of controlling the invasive South American tomato pinworm *Tuta absoluta*. PLoS ONE 7:e48068

Chailleux A, Biondi A, Han P, Tabone E, Desneux N (2013) Suitability of the pest–plant system *Tuta absoluta* (Lepidoptera: Gelechiidae)–tomato for *Trichogramma* (Hymenoptera: Trichogrammatidae) parasitoids and insights for biological control. J Econ Entomol 106:2310–2321

Charles JG (2012) Assessing the non-target impacts of classical biological control agents: is host-testing always necessary? Biocontrol 57:619–626

Colomo MV, Berta DC, Chocobar MJ (2002) El complejo de himenópteros parasitoides que atacan a la "polilla del tomate" *Tuta absoluta* (Lepidoptera: Gelechiidae) en la Argentina. Acta Zool Lilloana 46:81–92

Consoli FL, Parra JRP, Hassan SA (1998) Side-effects of insecticides used in tomato fields on the egg parasitoid *Trichogramma pretiosum* Riley (Hym, Trichogrammatidae), a natural enemy of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). J Appl Entomol 122:43–47

D'Hervé FE, Aquino DA (2016) Detección de hiperparasitoides de *Mastrus ridens* (Hymenoptera: Ichneumonidae) y *Ascogaster quadridentata* (Hymenoptera: Braconidae) en el Alto Valle del Río Negro, Argentina. Rev Mus Argent Cienc Nat Nueva Ser 17:153–158

Daane KM, Wang XG, Biondi A, Miller B, Miller JC, Riedl H et al (2016) First exploration of parasitoids of *Drosophila suzukii* in South Korea as potential classical biological agents. J Pest Sci 89:823–835

De Santis L (1967) Catálogo de los Himenópteros Argentinos de la Serie Parasitica, incluyendo Bethyloidea. Comisión de Investigaciones Científicas, La Plata

De Santis L (1979) Catálogo de los himénopteros calcidoideos de América al sur de los Estados Unidos. Publicación Especial Comisión de Investigaciones Cientificas Provincia de Buenos Aires

De Santis L (1983) Un nuevo género y dos nuevas especies de Eulofidos Neotropicales (Insects, Hymenoptera). Rev Peru Entomol 26:4

De Santis L (1989) Catálogo de los Himenopteros Calcidoides (Hymenoptera) al sur de los Estados Unidos, segundo suplemento. Catalogue of the Chalcidoidea (Hymenoptera) of America south of the United States, second supplement. Acta Entomol Chil 15:47
De Santis L, Fidalgo P (1994) Catálogo de los himenópteros calcidoideos de América al sur de los Estados Unidos. Tercer suplemento. Ser Acad Nac Agron Vet 13:1–154
De Santis L, Monetti NC (2008) Lista de himenópteros parasitoides y depredadores de los insectos de argentina: primer suplemento. En: Contribuciones taxonómicas en órdenes de insectos hiperdiversos 5:103
Debach P, Rosen D (1991) Biological control by natural enemies. Cambridge University Press, Cambridge
Desneux N, Decourtye A, Delpuech JM (2007) The sublethal effects of pesticides on beneficial arthropods. Annu Rev Entomol 52:81–106
Desneux N, Starý P, Delebecque CJ, Gariepy TD, Barta RJ, Hoelmer KA, Heimpel GE (2009) Cryptic species of parasitoids attacking the soybean aphid (Hemiptera: Aphididae) in Asia: *Binodoxys communis* and *Binodoxys koreanus* (Hymenoptera: Braconidae: Aphidiinae). Ann Entomol Soc Am 102:925–936
Desneux N, Wajnberg E, Wyckhuys KAG, Burgio G, Arpaia S et al (2010) Biological invasion of European tomato crops by *Tuta absoluta*: ecology, geographic expansion and prospects for biological control. J Pest Sci 83:197–215
Desneux N, Luna MG, Guillemaud T, Urbaneja A (2011) The invasive South American tomato pinworm, *Tuta absoluta*, continues to spread in Afro-Eurasia and beyond: the new threat to tomato world production. J Pest Sci 84:403–408
Desneux N, Blahnik R, Delebecque CJ, Heimpel GE (2012) Host phylogeny and specialisation in parasitoids. Ecol Lett 15:453–460
Doutt RL (1948) The distribution of *Copidosoma koehleri* Blanchard. Pan-Pac Entomol 24:34–35
Dzhanokmen KA (2017) Pteromalids (Hymenoptera: Chalcidoidea: Pteromalidae) of Syrdarya-Kyzylkum and Betpakdala-Moyynkum desert territories in southern Kazakhstan. Isr J Entomol 47:107–131
Fernández F, Sharkey MJ (2006) Introducción a los Hymenoptera de la Región Neotropical. Soc Colomb de Entomol y UNAL, p 894
Fernández-Triana J, Janzen DH, Hallwachs W, Whitfield JB, Smith MA, Kula R (2014) Revision of the genus *Pseudapanteles* (Hymenoptera, Braconidae, Microgastrinae), with emphasis on the species in Area de Conservación Guanacaste, northwestern Costa Rica. ZooKeys 446:1–82
Ferrer F (2001) Biological control of agricultural insect pests in Venezuela; advances, achievements, and future perspectives. Biocontrol News Inf 22:67–74
García Roa F (1989) Plagas del tomate y su manejo. ICA Palmira, Colombia
Ghoneim K (2014) Parasitic insects and mites as potential biocontrol agents for a devastive pest of tomato, *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) in the world: a review. Int J Recent Res Appl Stud 19:36–68
Girod P, Lierhmann O, Urvois T, Turlings TC, Kenis M, Haye T (2018) Host specificity of Asian parasitoids for potential classical biological control of *Drosophila suzukii*. J Pest Sci 91:1241–1250
Gordh G (1979) Family Encyrtidae. In: Krombein KV, Hurd PD Jr, Smith DR, Burks BD (eds) Catalog of Hymenoptera in America North of Mexico, vol 1. Smithsonian Institution Press, Washington, pp 890–967
Guedes RNC, Picanço MC (2012) The tomato borer *Tuta absoluta* in South America: pest status, management and insecticide resistance. EPPO Bull 42:211–216
Guerrieri E, Noyes JS (2005) Revision of the European species of *Copidosoma* Ratzeburg (Hymenoptera: Encyrtidae), parasitoids of caterpillars (Lepidoptera). Syst Entomol 30:97–174
Guerrieri E, Giorgini M, Cascone P, Carpenito S, van Achterberg C (2016) Species diversity in the parasitoid genus *Asobara* (Hymenoptera: Braconidae) from the native area of the fruit fly pest *Drosophila suzukii* (Diptera: Drosophilidae). PLoS ONE 11:e0147382
Han P, Zhang YN, Lu ZZ, Wang S, Ma DY, Biondi A, Desneux N (2018) Are we ready for the invasion of *Tuta absoluta*? Unanswered key questions for elaborating an Integrated Pest Management packages in Xinjiang province, China. Entomol Gen 38:113–125
Han P, Bayram Y, Shaltiel-Harpaz L, Sohrabi F, Saji A et al (2019) *Tuta absoluta* continues to disperse in Asia: damage, ongoing management and future challenges. J Pest Sci. https://doi.org/10.1007/s10340-018-1062-1
Hanson PI, Gauld D (1995) Hymenoptera of Costa Rica. Oxford University Press, Oxford
Hansson C (1997) Survey of *Chrysocharis* Förster and *Neochrysocharis* Kurdjumov (Hymenoptera, Eulophidae) from Mexico, including eight new species. Misc Zool 20:81–95
Hardwick S, Ferguson CM, McNeill MR, Phillips CB (2016) Using mass-emergence devices to introduce an insect biocontrol agent to a new region and assist its dispersal. J Pest Sci 89:965–976
Hawikins BA, Cornell HV (2000) Theoretical approaches to biological control. Cambridge University Press, Cambridge
Heimpel GE, Cock MJ (2018) Shifting paradigms in the history of classical biological control. Biocontrol 63:27–37
Herting B (1975) Lepidoptera, Part 1 (Microlepidoptera). A catalogue of parasites and predators of terrestrial arthropods. Section A. Host or Prey/Enemy, vol 6. Commonwealth Agricultural Bureaux, Commonwealth Institute of Biological Control, 218 pp
Herting B (1976) Lepidoptera, Part 2 (Macrolepidoptera). A catalogue of parasites and predators of terrestrial arthropods. Section A. Host or Prey/Enemy, vol 7. Commonwealth Agricultural Bureaux, Commonwealth Institute of Biological Control, 221 pp
Holzschuh A, Steffan Dewenter I, Tscharntke T (2010) How do landscape composition and configuration, organic farming and fallow strips affect the diversity of bees, wasps and their parasitoids? J Anim Ecol 79:491–500
Hutchison D, Moratorio M, Martin JM (1989) Morphology and biology of *Trichogrammatoidea bactrae* (Hymenoptera: Trichogrammatidae), imported from Australia as a parasitoid of pink bollworm (Lepidoptera: Gelechiidae) eggs. Ann Entomol Soc Am 83:46–54
Iannaconne OJ, Lamas MG (2003) Toxicological effects of extracts of Peruvian peppertree (*Schinus molle*) and lantana (*Lantana camara*) on *Chrysoperla externa* (Neuroptera: Chrysopidae), *Trichogramma pintoi* Hymenoptera: Trichogrammatidae) and *Copidosoma koehleri* (Hymenoptera: Encyrtidae) in Perú. Agric Téc 63(4):347–360
IDMA—Instituto de Desarrollo y Medio Ambiente Perú (2018) Control Biológico. http://idmaperu.org/idma/recursos/. Accessed 30 Sept 2018
Kenis M, Hurley BP, Hajek AE, Cock MJW (2017) Classical biological control of insect pests of trees: facts and figures. Biol Invasions 19:3401–3417
Klein Koch C (1977) Aspectos generales del control biológico e integrado de plagas en Chile. Bol Serv Plagas 3:121–132
Lai PY, Funasaki GY (1985) Introductions for biological control in Hawaii 1981 and 1982. Proc Hawaii Entomol Soc 24:83–86
Lietti MM, Botto E, Alzogaray RA (2005) Insecticide resistance in argentine populations of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Neotrop Entomol 34:113–119
Louda SM, Pemberton RW, Johnson MT, Follett P (2003) Nontarget effects—the Achilles' heel of biological control? Retrospective analyses to reduce risk associated with biocontrol introductions. Annu Rev Entomol 48:365–396

Luft PA (1993) Experience affects oviposition in *Goniozus nigrifemur* (Hymenoptera: Bethylidae). Ann Entomol Soc Am 86(4):497–505

Luft PA (1996) Fecundity, longevity, and sex ratio of *Goniozus nigrifemur* (Hymenoptera: Bethylidae). Biol Control 7(1):17–23

Luft E, Luna MG, Galise G, Speranza S, Virla E (2015) Mortalidad natural de huevos de la polilla del tomate, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) en Argentina e Italia, y primera mención de *Encarsia porteri* (Mercet) (Hymenoptera: Aphelinidae) afectando sus poblaciones. Rev Fac UNCuyo 47:219–229

Luna MG, Wada VI, La Salle J, Sánchez NE (2011) *Neochrysocharis formosa* (Westwood) (Hymenoptera: Eulophidae), a newly recorded parasitoid of the tomato moth, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), in Argentina. Neotrop Entomol 40:412–414

Luna MG, Pereyra PC, Coviella CE, Nieves E, Savino V, Salas Gervassio NG, Luft E, Virla E, Sánchez NE (2015) Potential of biological control agents against *Tuta absoluta* (Lepidoptera: Gelechiidae): current knowledge in Argentina. Fla Entomol 98:489–494

Mansour R, Brévault T, Chailleux A, Cherif A, Grissa-Lebdi K et al (2018) Occurrence, biology, natural enemies and management of *Tuta absoluta* in Africa. Entomol Gen 38:83–111

Mason WRM (1981) The polyphyletic nature of *Apanteles* Foerster (Hymenoptera: Braconidae): a phylogeny and reclassification of Microgastrinae. Mem Entomol Soc Can 115:1–147. https://doi.org/10.4039/entm113115fv

Mills NJ (1994) Parasitoid guilds: defining the structure of the parasitoid communities of endopterygote insect hosts. Environ Entomol 23:1066–1083

Miranda MMM, Picanço M, Zanuncio JC, Guedes RNC (1998) Ecological life table of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Biocontrol Sci Technol 8(4):597–606

Morales J, Rodríguez D, Cantor F (2013) Estandarización de la cría masiva de *Apanteles gelechiidivoris* Marsh (Hymenoptera: Braconidae) para el control de *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae). Rev Fac Cienc Básicas 9:20–37

Morales J, Muñóz L, Rodríguez D, Cantor F (2014) Acción Combinada de feromona sexual y de avispas *Apanteles Gelechiidivoris* para el control de *Tuta absoluta* en cultivos de tomate bajo invernadero. Acta Biol Colomb 19:175–184

Nagaraja H, Nagarkatti S (1973) A key to some new world species of *Trichogramma* (Hymenoptera: Trichogrammatidae), with descriptions of four new species. Proc Entomol Soc Wash 75:288–297

Nakao HK, Funasaki GY (1979) Introductions for biological control in Hawaii: 1975 and 1976. Proc Hawaii Entomol Soc 13:125–128

Nakao HK, Funasaki GY, Higa SY, Lai PY (1981) Introductions for biological control in Hawaii 1977 and 1978. Proc Hawaii Entomol Soc 23:425–430

Nechols JR, Andres LA, Beardsley JA, Goeden RD, Jackson CJ (1995) Biological control in the Western United States, p 357

Noyes JS (1988) Encyrtidae (Insecta: Hymenoptera). Fauna N Z 13:188

Noyes JS (2018) Universal Chalcidoidea database. World Wide Web electronic publication http://www.nhm.ac.uk/chalcidoids. Accessed on 15 Aug 2018

Noyes JS, Hayat M (1994) Oriental mealybug parasitoids of the Anagyrini (Hymenoptera: Encyrtidae). CAB International, Oxon

Oatman ER, Platner GR (1989) Parasites of the potato tuberworm, tomato pinworm, and other closely related gelechiids. Proc Hawaii Entomol Soc 29:23–30

Ozawa A, Ota M, Kobayashi H (2002) Hyperparasitism of *Neochrysocharis formosa* (Westwood) on the primary parasitoid, *Diglyphus isaea* Walker, of the American serpentine leafminer, *Liriomyza trifolii* (Burgess). Annu Rep Kanto-Tosan Plant Prot Soc 49:109–112

Parra JRP, Zucchi RA (2004) *Trichogramma* in Brazil: feasibility of use after twenty years of research. Neotrop Entomol 33:271–281

Parra JRP, Botelho PSM, Corrêa-Ferreira BS, Bento JMS (eds) (2002) Controle Biológico no Brasil: Parasitoides e Predadores, 1st edn. Manole

Passos LC, Soares MA, Collares LJ, Malagoli I, Desneux N, Carvalho GA (2018) Lethal, sublethal and transgenerational effects of insecticides on Macrolophus basicornis, predator of Tuta absoluta. Entomol Gen 38(2):127–143

Peck O (1963) A catalogue of the nearctic Chalcidoidea (Insecta; Hymenoptera). Can Entomol (Suppl) 30:1–1092

Peters RS, Baur H (2011) A revision of the *Dibrachys cavus* species complex (Hymenoptera: Chalcidoidea, Pteromalidae). Zootaxa 2937:1–30

Pinto JD (1999) Systematic of the North American species of *Trichogramma* Westwood (Hymenoptera: Trichogrammatidae). Mem Entomol Soc 22:1–187

Pintureau B, Gerding M, Cisternas E (1999) Description of three new species of *Trichogrammatidae* (Hymenoptera) from Chile. Can Entomol 131(1):53–63

Plant Health Australia (2015) *Tuta absoluta* fact sheet. http://www.planthealthaustralia.com.au/pests/tomato-leaf-miner-tuta-absoluta. Accessed on 10 Oct 2018

Querino RB, Zucchi RA (2003) New species of *Trichogramma* Westwood (Hymenoptera: Trichogrammatidae) associated with lepidopterous eggs in Brazil. Zootaxa 163:1–10

Querino RB, Zucchi RA (2004) *Trichogramma* species (Hymenoptera: Trichogrammatidae) collected in suction trap in forest reserve. Neotrop Entomol 33:451–455

Querino RB, Zucchi RA (2011) Guia de Identificação de *Trichogramma* para o Brasil. Embrapa Informação Tecnológica, Brasília, DF

Riquelme Virgala MB, Botto E (2010) Estudios biológicos de *Trichogrammatoidea bactrae* Nagaraja (Hymenoptera: Trichogrammatidae), parasitoide de huevos de *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae). Neotrop Entomol 39:612–617

Roditakis E, Vasakis E, García-Vidal L, del Rosario Martínez-Aguirre M, Rison JL, Haxaire-Lutun MO, Nauen R, Tsagkarakou A, Bielza P (2018) A four-year survey on insecticide resistance and likelihood of chemical control failure for tomato leaf miner Tuta absoluta in the European/Asian region. J Pest Sci 91(1):421–435

Rossi Stacconi MV, Amiresmaeili N, Biondi A, Carli C, Caruso S et al (2018) Biological control of the invasive spotted wing *Drosophila* trough augmentative releases of the cosmopolitan parasitoid *Trichopria drosophilae*. Biol Control 117:188–196

Rothman LD, Darling DC (1990) Parasitoids of the golden rod gall moth: effects of scale on spatial density dependence. Oecologia 83:1–6

Salas Gervassio NG (2017) Perspectivas del uso del endoparasitoide nativo *Pseudapanteles dignus* (Muesebeck) (Hymenoptera: Braconidae) para el control biológico de la polilla del tomate *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Evaluación a campo. Doctoral dissertation, UNLP, Buenos Aires

Salas Gervassio NG, Luna MG, Lee S, Salvo A, Sánchez NE (2016) Trophic web associated with the South American tomato moth *Tuta absoluta*: implications for its conservation biological control in Argentina. Agric For Entomol 18:137–144

Sankarganesh E, Firake DM, Sharma B, Verma VK, Behere GT (2017) Invasion of the South American Tomato Pinworm, *Tuta absoluta*, in northeastern India: a new challenge and biosecurity concerns. Entomol Gen 36:335–345

Santana PA, Kumar L, Da Silva RS, Picanço MC (2019) Global geographic distribution of Tuta absoluta as affected by climate change. J Pest Sci. https://doi.org/10.1007/s10340-018-1057-y

Savino V, Coviella C, Luna MG (2012) Reproductive biology and functional response of *Dineulophus phtorimaeae*, a natural enemy of the tomato moth, *Tuta absoluta*. J Insect Sci 12:1–14

Savino V, Luna MG, Salas Gervassio NG, Coviella C (2016) Interspecific interactions between two *Tuta absoluta* (Lepidoptera: Gelechiidae) larval parasitoids with contrasting life histories. Bull Entomol Res 107(1):32–38

Silva DB, Bueno VHP, Caldeira Lins J Jr, van Lenteren JC (2015) Life history data and population growth of *Tuta absoluta* at constant and alternating temperatures on two tomato lines. Bull Insectol 68:223–232

Silva DB, Bueno VHP, Montes FC, van Lenteren JC (2016) Population growth of three mirid predatory bugs feeding on eggs and larvae of *Tuta absoluta* on tomato. Biocontrol 61:545–553

Simberloff D, Stiling P (1996) How risky is biological control? Ecology 77:1965–1974

Siqueira HA, Guedes RN, Picanco MC (2000) Insecticide resistance in populations of *Tuta absoluta* (Lepidoptera: Gelechiidae). Agric For Entomol 2:147–153

Soares MA, Campos MR, Passos LC, Carvalho GA et al (2019) Botanical insecticide and natural enemies: a potential combination for pest management against Tuta absoluta. J Pest Sci. https://doi.org/10.1007/s10340-018-01074-5

Sylla S, Brévault T, Bal AB, Chailleux A, Diatte M, Desneux N, Diarra K (2017) Rapid spread of the tomato leafminer, *Tuta absoluta* (Lepidoptera: Gelechiidae), an invasive pest in Sub-Saharan Africa. Entomol Gen 36:269–283

Tena A, García-Bellón J, Urbaneja A (2017) Native and naturalized mealybug parasitoids fail to control the new citrus mealybug pest *Delottococcus aberiae*. J Pest Sci 90:659–667

Thancharoen A, Lankaew S, Moonjuntha P, Wongphanuwat T, Sangtongpraow B, Ngoenklan R, Kittipadakul P, Wyckhuys KAG (2018) Effective biological control of an invasive mealybug pest enhances root yield in cassava. J Pest Sci 91:1199–1211

Thiery D, Desneux N (2018) Host plants of the polyphagous grape berry moth *Lobesia botrana* during larval stage modulate moth egg quality and subsequent parasitism by the parasitoid *Trichogramma cacoeciae*. Entomol Gen 38:47–59

Thompson WR (1955) A catalogue of the parasites and predators of insect pests. Commonwealth Agricultural Bureaux, The Commonwealth Institute of Biological Control, Ottawa, pp 191–332

Uchoa-Fernandes MA, de Campos WG (1993) Parasitoides de larvas e pupas da traça-do-tomateiro, *Scrobipalpuloides absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae). Rev Bras Entomol 37:399–402

van Lenteren JC (2012) The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake. Biocontrol 57:1–20

van Lenteren JC, Manzaroli G (1999) Evaluation and use of predators and parasitoids for biological control of pests in greenhouses. In: Albajes R, Gullino ML, van Lenteren JC, Elad Y (eds) Integrated pest and disease management in greenhouses crops. Kluwer, Dordrecht, pp 183–201

van Lenteren JC, Hemerik L, Lins J, Bueno VHP (2016) Functional responses of three neotropical mirid predators to eggs of *Tuta absoluta* on Tomato. Insects 7:34

van Lenteren JC, Bolckmans K, Kohl J, Ravensberg W, Urbaneja A (2018) Biological control using invertebrates and microorganisms: plenty of new opportunities. Biocontrol 63:39–59

Vargas HC (1970) Observaciones sobre la biología y enemigos naturales de la polilla del tomate, *Gnorimoschema absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Idesia 1:75–110

Whiteside EF (1981) The results of competition between two parasites of the potato tuber moth, *Phthorimaea operculella* (Zeller). J Entomol Soc S Afr 44:359–365

Wyckhuys KA, Lu Y, Morales H, Vazquez LL, Legaspi JC, Eliopoulos PA, Hernandez LM (2013) Current status and potential of conservation biological control for agriculture in the developing world. Biol Control 65(1):152–167

Xian X, Han P, Wang S, Zhang G, Liu W, Desneux N, Wan F (2017) The potential invasion risk and preventive measures against the tomato leafminer *Tuta absoluta* in China. Entomol Gen 36:319–333

Yu DSK, van Achterberg C, Horstmann K (2012) Taxapad. Ichneumonoidea 2011. Database on flash-drive. http://www.taxapad.com. Ottawa, Ontario, Canada. Accessed on 16 Aug 2018

Zappalà L, Bernardo U, Biondi A, Cocco A, Deliperi S et al (2012) Recruitment of native parasitoids by the exotic pest *Tuta absoluta* (Meyrick) in Southern Italy. Bull Insectol 65:51–61

Zappalà L, Biondi A, Alma A, Al-Jboory IJ, Arnó J et al (2013) Natural enemies of the South American moth, *Tuta absoluta*, in Europe, North Africa and Middle East, and their potential use in pest control strategies. J Pest Sci 86:635–647

Zucchi RA, Monteiro RC (1997) O gênero *Trichogramma* na América do Sul. In: Parra JRP, Zucchi RA (eds) *Trichogramma* e o Controle Biológico Aplicado. FEALQ, Sao Paulo, pp 41–66