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RESEARCH ARTICLE

Parasitic insects and mites as potential biocontrol agents for a devastative pest of tomato, Tuta absoluta Meyrick (Lepidoptera: Gelechiidae) in the world: a review

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Abstract

The tomato leafminer *Tuta absoluta* is extremely difficult to control using chemical insecticides because larvae mine within plant tissue and are thus protected at least from contact insecticides, but also because of its ability to develop resistance to insecticides makes its control quite challenging. Thus, parasitoids are a very important component of the natural enemy complex of *T. absoluta* and have been the most common type of natural enemies introduced for biological control of it. In the present review, the importance of different egg-, larval- and pupal-parasitoids, belonging to several insect orders and families, as well as some Pyemotidae mites, was discussed. Research efforts and application works for biocontrol of *T. absoluta* in European, North African and Middle East countries, as well as the native home, South American countries, had been reviewed. Some considerations were presented, such as the parasitism mechanisms, factors affecting the parasitic efficiency, interference or interaction between parasitoids and some other natural enemies, side-effects of synthetic and botanical pesticides on parasitoids and conservation of indigenous natural parasitoids of *T. absoluta*.

Introduction

The tomato leafminer or American tomato pinworm, *Tuta absoluta* (=*Scrobipalpula absoluta* = *Scrobipalpuloides absoluta*)(Meyrick) (Lepidoptera: Gelechiidae), is a native devastating pest of South America, particularly to the tomato *Solanum lycopersicum* L. (or *Lycopersicon esculentum* (Mill.) (Gomide et al., 2001; Desneux et al., 2010; Gontijo et al., 2013; Lobos et al., 2013). It may be described as an intercontinental pest. Although *T. absoluta* is an endemic Neotropical pest, it has acquired a wider geographical distribution after its unintended introduction in other tomato production regions (Urbaneja et al., 2007; Speranza et al., 2009; Desneux et al., 2010). Since its first detection in Europe in late 2006 (Iberian Peninsula) (Urbaneja et al., 2007; Arnó and Gabarra, 2011), it has expanded very quickly in three years (2007-2009) to many countries in center and north Europe (Garcia-Mari and Vercher, 2010). Moreover, it has become an economically important pest in the major tomato-producing countries in the Mediterranean Basin countries of Europe and North Africa (Torres et al., 2001; Mallia, 2009; Desneux et al., 2010; Seplyarsky et al., 2010; Taha et al., 2012; Hanafy and El-Sayed, 2013; Dahliz et al., 2013; Guenaoui et al., 2013). In addition, the pest was reported in several Middle East, African and Asian countries (Desneux et al., 2011a; Al-Turaihi, 2011; Baniameri and Cheraghian, 2012; Mahmoud, 2013; Pfeiffer et al., 2013; EPPO, 2013). This pest causes a very high level of damage (quantity and quality) to tomato crops (Guedes and Picanço, 2012; Megido et al., 2012), particularly if no control measures are adopted (Desneux et al., 2011a; Öztemiz, 2012; Mollá, 2013). Beside tomato, *T. absoluta* is also able to attack and cause damage on different genera and species of the Solanaceae plants (eggplant, sweet pepper, potato and tobacco) (Garzia et al., 2012). In the Mediterranean basin, it infests also other plants (Desneux et al., 2010).

The primary *T. absoluta* management strategy in most native home, South America, or invaded European, African and Asian countries, is chemical control (Lietti et al., 2005; Siqueira et al., 2000a, 2001). However, pesticides are only partially successful because of the general endophytic behaviour of the larval instars (Lietti et al., 2005; Silva et al., 2011). Also, the resistance development in this pest to chemicals had been reported by several authors (Siqueira et al., 2000a,b, 2001; Lietti et al., 2005; Bielza, 2010; Öztemiz, 2012). Application of a pheromone-based mating disruption technique also provide poor results (Cocco et al., 2013). The prophylactic tools may be effective and eco-friendly way to control this invasive pest (Cherif et al., 2013). One explanation has been recently provided by the demonstration of a parthenogenetic reproduction in *T. absoluta*, from the research group in Gembloux Agro-Bio Tech (ULg) (Backer et al., 2014).

Because there is a real need to improve crop protection against *T. absoluta* and in the meanwhile reducing the use of synthetic insecticidal compounds, researches aim at providing new perspectives to further biocontrol strategies against *T. absoluta* (Backer et al., 2014). Several biological control (BC) agents and integrated pest management (IPM) programs have been recently evaluated (Mollá et al., 2011; Vacas et al., 2011; Zappala et al., 2012a). BC agents (living antagonists-natural enemies: predators, parasitoids and pathogens) are considered as one possible solution of the *T. absoluta* crisis (Desneux et al., 2010; Öztemiz, 2013). This strategy offers a more sustainable and less expensive alternative to chemicals (Vivan et al., 2003; Medeiros et al., 2006; Bale et al., 2008; Urbaneja et al., 2012).

A parasitoid is an organism that spends a significant portion of its life history attached to or within a single host organism in a relationship that is in essence parasitic; unlike a true parasite, however, it ultimately sterilizes or kills, and sometimes consumes, the host (for some details, see Godfray, 1994; Gullan and Cranston, 2004, 2010). Parasitoids are a very important component of the natural enemy complex of insect pests and have been the most common type of natural enemy introduced for BC of insect pests (Van Driesche and Bellows, 1996). A number of parasitoids of leafminers have been recorded throughout the world (Shepard et al., 1998; Heimpel and Meloche, 2001). A brief outlook of the future research and applications of indigenous *T. absoluta* BC agents were provided (Zappalà et al., 2013). Objective of the present review deals with parasitic insects and mites as natural enemies and promising biocontrol agents against *T. absoluta* allover the major tomato-producing countries in the world. As necessary related aspects: parasitism mechanisms, factors affecting the parasitic efficiency, interference or interaction between parasitoids of *T. absoluta* and some other natural enemies, side-effects of synthetic and botanical pesticides on parasitoids of *T. absoluta* and conservation of indigenous natural parasitoids had been discussed.

1. Parasitic insects against *Tuta absoluta*:

Compared to larval and pupal parasitoids, egg parasitoids should be considered better, because if they are effective, they can rapidly reduce the commercial damage in the same way as insecticides; whereas the larval and pupal parasitoids will control the pest over time but attack the pest only once the damage has been done (Newton, 1998). It is important to point out that no parasitoids of *T. absoluta* adults have been reported in the available literature. The parasitic insects, as natural enemies or biocontrol agents, with special emphasis on *T. absoluta*, can be reviewed herein according to the pest infested stage beside to the insect orders and families.

1.1. Egg parasitoids

From the taxonomic point of view, all recorded egg parasitoids of T. absoluta have been belonged to the order Hymenoptera. However, virtually nothing is known about T. absoluta egg parasitoids belonging to other orders as seen in the literature. The most important *T. absoluta* egg parasitoids are found in the families Trichogrammatidae, Encyrtidae and Eupelmidae.

The **Trichogrammatidae** are a family of tiny wasps in the superfamily Chalcidoidea that include some of the smallest of all insects (for some information, see Pinto and Stouthamer, 1994; Pinto, 2006). Different Trichogrammatid species attack eggs of insects belonging to 11 orders, especially Hymenoptera, Neuroptera, Diptera, Coleoptera and Hemiptera (Flanders and Quednau, 1960). *Trichogramma* (commonly known as stingless wasps) represent about 80 genera with over 800 species worldwide. They occur naturally in a variety of habitats across the world (Knutson, 2005; Sumer et al., 2009). There have been more than a thousand papers published on *Trichogramma* and their use as biological control agents in the world (Knutson, 1997, 2005). Consoli et al. (2010**)** edited a comprehensive book in which the egg parasitoids *Trichogramma* gained a considerable interest through both basic and applied information. About 210 species of *Trichogramma* are signaled as natural enemies of a variety of agricultural and forest pests in many regions of the world and at least 12 species are widely used commercially in biological control programs (Smith, 1996; Pinto, 1998; Mills and Kuhlmann, 2004; Pratissoli et al., 2005; Kumar et al., 2009; Suckling and Brockerhoff, 2010**)**. The *Trichogramma* parasitoids, as biocontrol agents, can be produced quickly and affordably relative to other parasitoids, due to the short generation time and the fact that they can be easily reared on factitious hosts (Mansour, 2010). Success in biological control by *Trichogramma* depends on the taxonomic identification of these species. Recently, a molecular techniques were developed to resolve the taxonomic status of these parasitoids (Herz et al., 2007; España-Luna et al., 2008; Ávila-Rodríguez et al., 2009; Jeong et al., 2010; Ercan et al., 2011; Nasir et al., 2013; Zouba et al., 2013).

Trichogramma pretiosum (Riley) is a more general parasitoid, by which it is likely to parasitize a range of different species (Knutson, 2005). The biological characteristics, thermal requirements and parasitism capacity of it had been studied on eggs of different lepidopterans (Pastori et al., 2007; Bastos et al., 2010; Silva Altoé et al., 2012; Bueno et al., 2012). This egg parasitoid wasp has been widely used to control *T. absoluta* (Faria, 1992; Haji, 1997; Miranda et al., 1998; Pratissoli et al., 1998, 2003, 2005, 2006; Goncalves-Gervasio et al., 2000; Tissoli and Parra, 2001; Concalves-Gervasio, 2003; Faria et al., 2000, 2008; Torres et al., 2002; Garcia et al., 2005; Medeiros et al., 2006; Cabello et al., 2009a; Desneux et al., 2010; Molla et al., 2011; Öztemiz, 2012; Vasconcelos, 2013).

Trichogramma exiguum Pinto & Platner has a good parasitism efficiency against *Ephestia* (=*Anagasta*) *kuehniella* (Lepidoptera: Pyralidae) and Sitotroga cerealella (Lepidoptera: Gelechiidae)(Oliveira et al., 2005). Operational considerations for augmentation of this parasitic wasp was investigated for suppression of *Rhyacionia frustrana* (Lepidoptera: Tortricidae) (Philip and Orr, 2008). Effects of some environmental factors on its development and adult survival had been studied (Suh et al., 2000; Witting-Bissinger et al., 2008). This egg parasitic wasp was reported as biocontrol agent against *T. absoluta* (Navarro, 1988; Desneux et al., 2010; Öztemiz, 2012).

Trichogramma achaeae Nagaraja & Nagarkatti has a worldwide distribution (Nagaraja et al., 2002). It is an egg parasitoid of 26 Lepidoptera species belonging to 10 families and has been evaluated as a biological control agent of different lepidopteran pests (Jalali et al., 2002; Shivaleela and Patil, 2003; Chandrashekhar et al., 2003; Cabello et al., 2009a,b). This parasitic wasp was observed parasitizing on *T. absoluta* and may be a potential parasitoid for controlling it (Faria et al., 2008; Desneux et al., 2010; Morley et al., 2010; Kabiri et al., 2010; Zimmermann et al., 2010; Cabello et al., 2010, 2012a, b; Sharidi et al., 2011; Polaszek et al., 2012; Calvo et al., 2012; Trottin-Caudal et al., 2012; Öztemiz, 2012; Thi Khanh et al., 2012; Chailleux et al., 2012, 2013).

Trichogramma evanescens Westwood can taxonomically considered as a synonym of *Trichogramma turkestanica* Meyer (Ercan et al., 2013) or *Trichogramma euproctidis* Girault (Hansen, 2000; Hansen and Jensen, 2002). Sequence of the behavioral events and progeny production (Ahmed, 2008), as well as the dispersal ability and parasitization performance (Doyon and Boivin, 2005; Ayvaz et al., 2008; Mandour et al., 2008) of *T. evanescens* had been investigated. This egg parasitoid was used to control *T. absoluta* (Silva, 1999; Polaszek et al., 2012; Payer et al., 2012; Oztemiz, 2012, 2013). Several biological and ecological studies of *T. turkestanica* had been carried out (Hansen, 2000; Ferracini et al., 2006; Martel, 2007; Gingras et al., 2008; Sayed et al., 2011). The latter egg parasitoid was recorded on or used to control *T. absoluta* (Silva, 1999). Some studies had been carried out on mating behaviour (Martel et al., 2010), feeding behaviour (Lessard and Boivin, 2013) of *T. euproctidis*. In addition, the effect of host availability on the biology (Schöller, 2009) as well as the effect of ionizing (Gamma) and non-ionizing (UV) radiation on the development (Tuncbilek et al., 2012) were studied. The latter parasitoid wasp was recorded on or used to control *T. absoluta* (Chailleux et al., 2012; Polaszek et al., 2012).

Trichogramma bourarachae Pintureau & Babault gained some research attention to investigate its biological potentialities (Bourarach et al., 1998), the potential effect of flowering plants on its activity (Herz et al., 2005), parasitism rate (Milonas et al., 2009) and effects of some synthetic pesticides and biopesticides (Ksentini et al., 2010). It was tested against some lepidopterous insect pests in Sudan (Kehail and Abdelgader, 2010). This egg parasitoid has been used for controlling *T. absoluta* (Silva, 1999; Polaszek et al., 2012; Zouba et al., 2013).

Trichogramma cacoeciae Marchal was used as an indicator species for testing the side-effect of pesticides on beneficial arthropods (Hassan, 1998). Also, temperature-dependent differences in biological traits between two strains of *T. cacoeciae* (Pizzol et al., 2010), the parasitization rate (Hegazi and Khafagi, 2001) and field release as a part of biological control of codling moth, *Cydia pomonella* (Tortricidae, Lepidoptera)(Almatni et al., 2002) had been investigated. This egg parasitoid has been used to control *T. absoluta* (Zouba and Mahjoubi, 2010; Abbes et al., 2012; Öztemiz, 2012; Durán, 2013).

Trichogramma cordubensis Vargas & Cabello was used as a biological control agent for agricultural pests existing in the Azores islands had been studied (Garcia et al., 1995; Garcia and Tavares, 1997). Host suitability (Roriz et al., 2006) and the effect of female age on the parasitization capacity (Garcia et al., 2001**)** of this parasitoid had been studied. Trials for using this parasitoid to control *T. absoluta* had been conducted (Silva, 1999).

Trichogramma pintoi Voegele was reported as an egg parasitiod on *Lobesia* spp. (Lepidoptera: Tortricidae) in Ukraine (Fursov, 1994), on winter moth *Operophtera brumata* (Lepidoptera: Geometridae) in Iran (Alizadeh and Ebrahimi, 2004), on *P. xylostella* (Akbari et al., 2012) and on some other lepidopterans (Dadpour Moghanlou, 2002). Iannacone and Lamas (2003b) evaluated the toxicity of certain plant extracts on *T. pintoi* in Peru. This egg parasitoid was observed on or used to control *T. absoluta* (Silva, 1999; Desneux et al., 2010; Öztemiz, 2012).

Trichogramma minutum Riley is one of the most commonly egg parasitoids found in Europe (Flanders and Quednau, 1960). It is used throughout North America for the biological control of lepidopterous orchard and forest pests (Mills, 1998). Its parasitism role was studied (Smith and Hubbes, 1986; Nagarkatti et al., 2002; Quayle et al., 2003). As early as 1965, *T. minutum* was collected from Peru for using against *T. absoluta* in Chile (Klein Koch, 1977). The same egg parasitoid was recorded on the present pest in some other South American countries (Desneux et al., 2010) and Turkey (Öztemiz, 2012).

Trichogramma brassicae Bezdenko is used worldwide for the control of lepidopterous pests. It acts as an egg parasitoid of the carob moth, Apomyelois (Ectomyelois) ceratoniae (Lepidoptera: Pyralidae), in Iranian pomegranate orchards (Moezipour et al., 2008). Kuske et al. (2003) evaluated the effects of inundative releases of *T. brassicae* against the European corn borer, Ostrinia nubilalis (Lepidoptera: Crambidae). This egg parasitoid may attack *T. absoluta* (Potting et al., 2013).

Trichogrammatoidea bactrae Nagaraja is an egg parasitoid of the pink bollworm, *Pectinophora gossypiella* (Lepidoptera: Gelechiidae) in Australia (Hutchison et al., 1989). Some behavioural responses (Lu, 2010; Guo et al., 2011), its viability at different temperatures (Malik, 2001) and parasitization (Nadeem and Hamed, 2008) were determined. This egg parasitoid had been recorded on or used to control *T. absoluta* (Botto, 1998; Riquelme et al., 2006; Faria et al., 2008; Botto et al., 2009; Virgala and Botto, 2010; Desneux et al., 2010; Öztemiz, 2012).

Trichogramma dendrolimi Westwood, was reared on eggs of a factitious host, *Antheraea pernyi* (Lepidoptera: Saturniidae)(Park et al., 2000). Its host-acceptance behaviour is plastic (Qiu et al., 1999). Several factors affecting its parasitization capacity to eggs of some lepidopterans had been investigated (Liu et al., 1998; Hegazi and Khafagi, 2001). This egg parasitoid had been recorded on or used to control *T. absoluta* (Desneux et al., 2010; Öztemiz, 2012).

Trichogramma fasciatum (Perkins) was released to control the sugarcane borer Diatraca saccharalis (Lepidoptera: Crambidae)(Burrell and Mccormick, 1962). Among the most common parasitoids of Epiphyas postvittana (Lepidoptera: Tortricidae) in San Francisco Bay Area (USA) was T. fasciatum (Wang et al., 2012). This egg parasitoid had been recorded on or used to control T. absoluta (Desneux et al., 2010; Öztemiz, 2012).

Trichogramma lopezandinensis Sarmiento was recovered from eggs of the butterfly *Colias dimera* (Lepidoptera: Pieridae) in Colombia and was reared on *Sitotroga cerealella* (Lepidoptera: Gelechiidae) in the laboratory (Sarmiento, 1993). Some studies were carried out to use it for the control of potato tuber moth *Tecia solanivora* (Fovolny) (Lepidoptera: Gelechiidae)(Rincón and Lopez, 1999; Rubio et al., 2004). This egg parasitoid had been recorded on or used to control *T. absoluta* (Desneux et al., 2010; Öztemiz, 2012).

Trichogramma nerudai Pintureau and Gerding exhibited no preference for any of some lepidopterous pests (Torres and Gerding, 2000). In contrast, it may be useful in biological control programs of forest and agricultural insect pests, such as some lepidopterans, in several South America countries (Botto et al., 2004) and in Sudan (Kehail and Abdelgader, 2010). This egg parasitoid could be used to control *T. absoluta* (Querino and Zucchi, 2003; Tezze and Botto, 2004; Desneux et al., 2010; Öztemiz, 2012).

Trichogramma rojasi Nagaraja and Nagarkatti was reported as a biocontrol agent opening perspective to integrate biological control programs of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Cuba (Camera et al., 2010). Also, *T. rojasi* was collected from eggs of *Anticarsia gemmatalis* (Lepidoptera: Noctuidae) in Southern Brazil (Avanci et al., 2005). This egg parasitoid had been recorded on or used to control *T. absoluta* (Desneux et al., 2010; Öztemiz, 2012).

Trichogramma telengai Sorokina was recorded as an egg parasite of *Tortrix viridana* (Lepidoptera: Tortricidae) in the oak forests of the Crimea (Ivashov and Suslova, 1990). Recently, the maternal and grand-maternal photoperiodic responses of *T. telengai* were investigated in laboratory conditions (Voinovich et al., 2013). This egg parasitoid had been recorded on or used to control *T. absoluta* (Desneux et al., 2010; Öztemiz, 2012). In addition, Trichogramma urquijoi Cabello Garcia had been reported as an egg parasitoid for *Heliothis armigera* (Lepidoptera: Noctuidae)(Cabello, 1986). It was recorded on or used to control *T. absoluta* (Cabello et al., 2012).

Family **Encyrtidae** is one of the largest families in the superfamily Chalcidoidea (order Hymenoptera) and comprise about 3735 recognized species in 460 genera (Noyes, 2003). They are found throughout the world in virtually all habitats. All species are parasitoids but they are known to attack at least 153 insect families and 8 families of other arthropods. About 250 species of encyrtids have been used in biocontrol programmes involving nearly150 pest species (Noyes, 1997; Guerrieri and Noyes, 2000).

A mass release technique of the egg parasitic microwasp *Copidosoma koehleri* Blanchard on the potato moth *Phthorimaea operculella* (Lepidoptera: Gelechiidae) was developed (Pokharkar et al., 2003). The parasitism potential of this parasitoid on the same lepidopteran pest had been evaluated (Keasar, et al., 2006; Keasar and Sadeh, 2007; Keasar and Steinberg, 2008). This egg parasitoid was observed on or used for control *T. absoluta* (Sanchez-Aguirre and Palacios, 1996; Melo and Campos, 2000; Desneux et al., 2010; Öztemiz, 2012).

The microwasp *Copidosoma desantisi* Annecke & Mynhardt was observed as a parasitoid of *Ph. operculella* on potato foliage in south-eastern Queensland (Franzmann, 1980) and Egypt (Mandour, 1997; Mandour et al., 2008). Its longevity and fecundity on *Ph. operculella* (Cortez Madrigal et al., 1992) and the parasitization efficiency (Cortez Madrigal et al., 1991) had been evaluated. It is one of egg parasitoids attacking different developmental stages of *T. absoluta* in South America (Desneux et al., 2010; Öztemiz, 2012).

The parasitoid *Arrhenophagus* sp. was reported as a biocontrol agent for *Pseudaulacaspis pentagona* (Hemiptera: Diaspididae) in Hungary (Bayoumy et al., 2011). *Arrhenophagus albitibiae* Girault was recorded as natural parasite of *Aleurodicus dispersus* (Homoptera: Aleyrodidae) in Guam (western Pacific Ocean) (Nechols, 1983). Another parasitoid species in this genus, *Arrhenophagus chionaspidis* Aurivillius, was observed on *Aulacaspis yasumatsui* (Homoptera: Diaspididae) in Indonesia (Muniappan et al., 2012). Arrhenophagus sp. was recorded on or used to control *T. absoluta* (Desneux et al., 2010; Öztemiz, 2012).

Family **Eupelmidae** (order Hymenoptera) includs flightless parasitoid wasps of more than 905 described species in 45 genera. The larvae of the majority are primary parasitoids, commonly on beetle larvae, though many other hosts are attacked, including spiders. They are found throughout the world in virtually all habitats (Gibson, 1986, 1995; Kalina, 1981a, b). The parasitic wasp *Anastatus* sp. was reported on various lepidopteran and hemipterans in different parts of the world (Peigler, 1994; Zeng and Tang, 1998; Kim et al., 2011; Marchiori, 2003). Also, it was recorded as an egg parasitoid on or used for controlling *T. absoluta* (Desneux et al., 2010; Öztemiz, 2012).

1.2. Larval parasitoids

There is a large body of literature on the larval parasitoids of *T. absoluta* as classified in two insect orders, Hymenoptera and Diptera. With regard to Hymenoptera, different families (Encyrtidae, Eulophidae, Braconidae, Bethylidae, Chalcididae, Torymidae, Pteromalidae and Ichneumonidae) include several larval parasitoids while Tachanidae is only the family in order Diptera including some larval parasitoids of the present tomato leafminer.

1.2.1. Hymenoptera

In the family **Encyrtidae**, *Copidosoma* sp. was reared from larvae of *T. absoluta* collected in Argentina (Vasicek, 1983). The absolute and relative preferences of the parasitoid *C. koehleri* on *T. absoluta,* tuber moth *Ph. operculella* and tomato stemborer *Symmetrischema tangolias* (Lepidoptera: Gelechidae) were evaluated. Clear preference was observed for *Ph. operculella* but a minimum parasitism for *T. absoluta* (Sánchez-Aguirre and Palacios, 1996). *Copidosoma* sp., as a larval parasitoid, may be used to control *T. absoluta* (Vasicek, 1983; Sánchez-Aguirre and Palacios, 1996; Melo and Campos, 2000).

Family **Eulophidae** represents the largest one within the parasitic Hymenoptera, superfamily Chalcidoidea. Currently the family is represented by at least 4472 described species in 297 genera (Yefremova, 2002). The majority are primary parasitoids on a huge range of arthropods at all developmental stages. Several species of Eulophidae are important in biocontrol programs throughout the world (Noyes, 2011).

The genus *Necremnus* contains 30 species (Noyes, 1998) and comprises ectoparasitoids of lepidopterous larvae and of coleopterous larvae and prepupae (Zerova, 1992). The wasp *Necremnus tidius* (Walker) was recorded as a solitary ectoparasitoid of the cabbage seedpod weevil *Ceutorhynchus obstrictus* (Coleoptera: Curculionidae) in western Canada (Dosdall et al., 2007; Dosdall and Cárcamo, 2011; Mason et al., 2011**)**. This wasp was used as a larval parasitoid to control T. absoluta (Desneus et al., 2010; Straten et al., 2011; Klapwijk and Koppert, 2011; Giorgini et al., 2012; Ferracini et al., 2012; Zappala et al., 2012a; Calvo et al., 2012; Tavella et al., 2012). *Necremnus artynes* (Walker) is a biparental generalist solitary ectophagous parasitoid of lepidopteran leafminers. It has been reported over all Mediterranean countries (Gabarra et al., 2010; Desneux et al., 2012; Boualem et al., 2012). It was reported as a larval parasitoid for controlling *T. absoluta* (Molla et al., 2008; Desneux et al., 2010; Gabarra et al., 2010; Klapwijk and Koppert, 2011; Straten et al., 2011; Calvo et al., 2012a, Boualem et al., 2012; Ferracini et al., 2012; Zappala et al., 2012a, 2013; Öztemiz, 2012; Abbes and Chermiti, 2013; Balzan and Wackers, 2013; Dahliz et al., 2013; Guenaoui et al., 2013; Abbes et al., 2014).

The wasp *Chrysocharis pentheus* (Walker) was reported as both predator and parasite on the agromyzid pea pest Phytomyza horticola (Diptera: Agromyzidae) (Zhong and Sheng, 1990). As a natural parasite, it attacks the larvae of

Liriomyza trifolii (Diptera: Agromyzidae) (Ohno et al., 1999). The same parasitic wasp had been recorded as a biocontrol agent against *T. absoluta* (Giorgini et al., 2012).

Wasp species of the genus *Pnigalio* are ectoparasitoids, with solitary or gregarious larval development. Most of them are polyphagous and potentially important for biological control of lepidopterous leaf miners (Yegorenkova and Yefremova, 2012). The wasp *Pnigalio soemius* (Walker) (=*Pnigalio flavipes* = *Eulophus flavipes* = *Pnigalio punctiscuta*) is an ectoparasitoid of 89 leaf miner species and larvae of gall-makers from several insect orders (Noyes, 2002; Bernardo et al., 2008; Desneux et al., 2010). The same parasitic wasp was recorded as biological control agent for *T. absoluta* (Desneux et al., 2010; Giorgini et al., 2012; Zappala et al., 2012a). In addition, other parasitic wasps of *Pnigalio*, such as *Pnigalio* (=*Ratzeburgiola*) *christatus* (Ratzeburg) and *Pnigalio* (=*Ratzeburgiola*) *incompletes* (Boucek), had been used to control *T. absoluta* (Doganlar and Yigit, 2011; Öztemiz, 2012; Giorgini et al., 2012; Zappala et al., 2012a). Recently, *Pnigalio* sp. weas recorded on *T. absoluta* only at Mostaganem in Algeria (Guenaoui et al., 2013).

The wasp *Hemiptarsenus zilahisebessi* Erdös had been reported as a parasitoid of leaf miners from orders Coleoptera, Lepidoptera and Diptera. *H. zilahisebessi* was identified as a parasitoid of leaf miners, *Liriomyza sativae* (Zahiri et al., 2004) and L. trifolii (Asadi et al., 2006) in Iran. The same parasitic wasp was assessed as biological control agent against *T. absoluta* (Gabarra and Arno, 2010; Gabarra et al., 2010; Öztemiz, 2012; Guenaoui et al., 2013).

Tetrastichus planipennisi Yang is a gregarious larval endoparasitoid wasp which is native to North Asia. It is a parasitoid of the emerald ash borer *Agrilus planipennis* (Lepidoptera: Buprestidae) in North America (Yang et al., 2006; Bauer et al., 2008). In addition, *Tetrastichus howardi* (Olli) is a gregarious pupal parasitoid which has been recorded as a primary parasitoid or facultative hyperparasitoid associated with a great number of Lepidoptera pests of important crops (Baitha et al., 2004, Prasad et al., 2007). *Tetrastichus* sp. was recorded as a larval parasitoid on or used to control *T. absoluta* (Öztemiz, 2012).

More than 119 species in the large genus *Sympiesis* worldwide are mainly ectoparasitoids, hyperparasitoids, or larval and pupal parasitoids of various species of Lepidoptera, Coleoptera, and Diptera (Noyes, 1998). *Sympiesis striatipes* Ashmead is one of the most abundant ectoparasitoid on the gracillariid leafminers *Acrocercops* sp. and *Phyllonorycter* sp. in several Asian countries (Schauff et al., 1998) and the citrus leafminer *Phyllocnistis citrella* (Lepidoptera: Gracillariidae) in Japan (Mafi and Ohbayashi, 2010). However, Sympiesis sp. was observed as a larval ectoparasitoid on or used to control *T. absoluta* (Desneux et al., 2010; Boualem et al., 2012).

Biology (Gonçalves and Almeida, 2005) and eco-biology (Cheaha and Coakera, 1992; Haghani et al., 2007) of the larval parasitoid *Diglyphus isaea* (Walker) were studied. *D. isaea* is a primary parasitoid on agromyzid leaf miners and has been commercialized as a biological control agent (Heinz et al., 1993; Sher et al., 1996; Zhu et al., 2000). This larval parasitoid was used to control *T. absoluta* (Boualem et al., 2012; Guenaoui et al., 2013). In addition, *Diglyphus crassinervis* Erdös was recorded among parasitoids attacking the agromyzid leafminer flies (Strakhova et al., 2013). The latter parasitoid was reported as a biocontrol agent against *T. absoluta* (Giorgini et al., 2012**)**.

The naturally occurring larval ectoparasitoid *Dineulophus phthorimaeae* de Santis has been reported to have potential biocontrol efficiency in Argentina and Chile (Savino et al., 2012). This larval ectoparasitoid was reported as natural enemy to control *T. absoluta* (Benmoussa et al., 2009; Desneux et al., 2010; Luna et al., 2010, 2011, 2012; Savino et al., 2012; Öztemiz, 2012).

Neochrysocharis (*Clostrocerus*) *formosa* (Westwood) is now known from all continents except Australia, and has an extremely varied biology (Noyes, 2003). It is currently considered cosmopolitan after several introductions for biological control of more than 100 species in many orders, Coleoptera, Hemiptera, Diptera, Lepidoptera, and Hymenoptera (Quicke, 1997; Arakaki and Kinjo, 1998; Konishi, 1998). It was registered as a biological control agent for agromyzid leafminer pests (Saito et al., 1996; Ozawa et al., 2002). Several works had been achieved to use this parasitoid for controlling *T. absoluta* (Luna et al., 2005, 2011; Desneux et al., 2010; Öztemiz, 2012; Giorgini et al., 2012; Zappala et al., 2012a; Mahmoud, 2013; Dahliz et al., 2013; Guenaoui et al., 2013).

Some aspects of a native *Tetrastichus* sp. parasitic on the chondrilla gall midge *Cystiphura schmidti* (Diptera: Cecidomyiidae) were described in Australia (Moore, 1989). Its impact on the host and potential biological control was evaluated (Lee et al., 2002). The wasp *Tetrastichus* sp. was recorded as a larval ectoparasitoid on *T. absoluta* (Desneux et al., 2010).

The parasitoid *Zagrammosoma* sp. was collected from the lemon leaves infested with citrus leafminer, Ph. citrella in the Central Jordan Valley (Ateyyat, 2002). Also, it was recorded among parasitoids that associate with the leafminer fly, *L. sativae* found on lowland vegetables ecosystem in South Sumatra (Adam et al., 2010). This larval parasitoid was recorded on *T. absoluta* (Desneux et al., 2010; Öztemiz, 2012).

Stenomesius spp, and mainly *Stenomesius japonicus* (Ashmed), have a wide host range including Gelechiidae, Pyralidae and Gracillariidae (David and Stevens, 1992). Stenomesius sp. had been reported spontaneously attacking *T. absoluta* in infested tomatos (Arnó and Gabarra, 2010; Dahliz et al., 2013; Guenaoui et al., 2013). *Stenomesius* sp. near *japonicus* was recorded parasitizing *T. absoluta* (Biondi et al., 2013a).

As ectoparasitoids on *T. absoluta*, several other eulophids were reported, such as *Horismenus* sp. (Desneux et al., 2010), *Baryscapus bruchophagi* (Gahan) (Doganlar and Yigit, 2011; Öztemiz, 2012), Retisympiesis phthorimaea Blanchard (Desneux et al., 2010; Oztemiz, 2012, 2013), *Cirrospilus* sp. (Bloem and Spaltenstein, 2011; Kos and Trdan, 2011), *Elachertus inunctus* Nees (Desneux et al., 2010), *Closterocerus clarus* (Szelenyi) (Doganlar and Yigit, 2011; Öztemiz, 2012) and *Elasmus* sp. (Desneux et al., 2010).

The **Braconidae** is a family of parasitoid wasps (LaSalle and Gauld, 1993) and is one of the largest families in order Hymenoptera (Yu et al., 2006; Jones et al., 2009). Brachonid wasps are cosmopolitan and diverse in all areas (Wharton, 1993) but they are highly abundant in cool temperate regions (Quicke and Kruft, 1995). Most braconids are primary endoparasitoids of Lepidoptera larvae, although most holometabolous groups may be attacked. They have important role in the biological control of the phytophagous insect pests, particularly the economically important pests (Ghahari et al., 2006; Beyarslan et al., 2010; Ghahari and Fischer, 2011).

The braconid wasp *Bracon nigricans* Szépligeti is a larval ectoparasitoid of Lepidoptera species. The acute toxicity and sublethal effect of six bioinsecticides, used for controlling *T. absoluta*, were assessed on the fertility of *B. nigricans* (Biondi et al., 2012). The available literature contains other reports of its use to control the same pest (Öztemiz, 2012; Giorgini et al., 2012; Zappala et al., 2012a; Biondi et al., 2013a, b).

The braconid wasp *Bracon* (*Habrobracon*) *hebetor* Say is a gregarious larval ectoparasitoid of several species of Lepidoptera that are associated with stored products (Ghimire and Phillips, 2010). Some attempts to develop an alternative system to mass rear this parasitoid were achieved (Magro and Parra, 2004; Magro et al., 2006). This parasitoid wasp was observed on or used to control *T. absoluta* (Doganlar and Yigit, 2011; Öztemiz, 2012; Giorgini et al., 2012; Mahmoud, 2013; Dahliz et al., 2013).

The parasitic wasp *Bracon* (*Habrobracon*) *concolorans* (Marshall) has generally been referred to as *H.* (or *B.*) *nigricans* (Szepligeti) but recently the name *nigricans* has been synonymized under *concoloans* (Al-Jboory et al., 2012**)**. *B. concolorans* is known from a wide range of countries from western and southern Europe east to Russia (Primorsky) and China. It was found also in Tunisia, Iran and Turkey (for details, see Al-Jboory et al., 2012**)**. It is recorded from Jordan (Al-Jboory et al., 2012**)** and Sudan (Mahmoud, 2013) for the first time, attacking *T. absoluta*.

Also, other *Bracon* species, such as *Bracon lulensis* Berta & Colomo (Miranda et al., 1998; Berta and Colomo, 2000; Marchiori et al., 2003a; Desneux et al., 2010), *Bracon tutus* Berta & Colomo (Miranda et al., 1998; Berta and Colomo, 2000; Marchiori et al., 2003a; Desneux et al., 2010; Öztemiz, 2012), *Bracon lucileae* Marsh (Uchoa-Fernandes and Campos, 1993; Miranda et al., 1998; Berta and Colomo, 2000; Marchiori et al., 2003a; Desneux et al., 2010; Öztemiz, 2012), *Bracon* (*Glabrobracon*) *osculator* Nees (Giorgini et al., 2012; Öztemiz, 2012; Zappala et al., 2012a) and *Bracon didemie* Beyarslan (Doganlar and Yigit, 2011; Öztemiz, 2012; Yiğit et al., 2013) had been recorded among parasitoids attacking *T. absoluta* and can be used to control it.

All species of the genus *Agathis* are solitary koinobiont endoparasitoids of many concealed Lepidopterous larvae (Simbolotti and van Achterberg, 1999). *Agathis fuscipennis* (Zetterstedt) (=*Agathis glabricula* Thomson) is a polyphagous parasitoid living on many Lepidoptera families (Simbolotti and van Achterberg, 1999; Yu and van Achterberg, 2010). *A. fuscipennis* was observed as larval parasitoid on *T. absoluta* (Desneux et al., 2010; Loni et al., 2011; Giorgini et al., 2012).

The wasp *Chelonus* sp. is an egg-larval parasitoid of the cabbage looper *Trichoplusia ni* (Lepidoptera: Noctuidae). Some biological (Grossniklaus-Bürgin and Lanzrein, 1990), physiological (Jones, 1986) and parasitization (Buhler et al., 1985) studies of this parasitoid had been carried out. This wasp was recorded as a larval parasitoid on *T. absoluta* and can be used to control this pest (Berta and Colomo, 2000; Marchiori et al., 2003a; Desneux et al., 2010).

Earinus sp. was observed among three species parasitizing apple leafroller *Bonagota cranaodes* (Lepidoptera: Tortricidae) in southern Brazil (Botto et al., 2002). It was collected from the quinoa moth *Eurysacca melanocampta* (Lepidoptera: Gelechiidae) (Costa et al., 2009). Also, it was observed as a natural larval parasitoid of *T. absoluta* and may be used to control this pest (Marchiori et al., 2004, 2007; Desneux et al., 2010; Öztemiz, 2012).

Based on the characteristics of fecundity, daily oviposition and longevity, the braconid *Orgilus* sp. can be used for the control of *Ph. operculella* (Llanderal-Cázares et al., 2000). It was recorded as a larval parasitoid on *T. absoluta* and its release to control this pest is feasible (Berta and Colomo, 2000; Marchiori et al., 2003a; Desneux et al., 2010; Öztemiz, 2012).

Some other wasps in the family Braconidae had been recorded on or used to control *T. absoluta*, such as: *Apanteles gelechiidivoris* Marsh (Bajonero et al., 2008; Muñoz et al., 2009; Desneux et al., 2010; Riano, 2012), *Apanteles dignus* Muesebeck (Cardona and Oatman, 1971; Desneux et al., 2010), *Pseudapanteles dignus* (Muesebeck) (Maria et al., 2004; Botto, 2011; Luna et al., 2007, 2010, 2011; Sanchez et al., 2009; Desneux et al., 2010; Öztemiz, 2012; Nieves, 2013; Savino et al., 2013) and *Dolichogenidia gelechiidivoris* (Iannacone and Lamas, 2003a). In addition, three Argentina species of *Bracoiz* (*B. lulelzsis, B. tutus*, *B. lucileae*) parasitize larvae of *T. absoluta* (Berta and Colomo, 2000).

The **Bethylidae** are a family of aculeate wasps (order Hymenoptera) widely distributed throughout the world, but the majority of species occur in tropical regions. The family comprises about 100 genera and about 2400 described species (Mugrabi and Azevedo, 2010). Bethylid species have attracted the attention of applied entomologists because their hosts (larvae, and more rarely pupae, of Lepidoptera and Coleoptera) include many important pests of crops and stored products (Perez-Lachaud and Hardy, 1999). Some of biological aspects of *Parasierola* (*Goniozus*) *nigrifemur* Ashmead were studied (Luft, 1996; Papaj, 2005). This parasitoid wasp was observed on or used to control *T. absoluta* (Miranda et al., 1998; Desneux et al., 2010; Öztemiz, 2012).

The family **Chalcididae** (order Hymenoptera) is cosmopolitan in distribution, and particularly diverse in tropical lowland areas. It comprises about 1500 species in nearly 90 genera (Askew, 1994). All Chalcididae are parasitoids of larvae or pupae of other insects, such as Lepidoptera, Diptera, Coleoptera, Neuroptera, and Hymenoptera (Grissell and Schauff, 1990). *Brachymeria* is a genus of chalcidid parasitic wasps. All species are parasites of insect larvae. The chalcid wasp *Brachymeria secundaria* (Ruschka) was observed as a larval parasitoid on *Malacosoma neustria* (Lepidoptera: Lasiocampidae) in Turkey (Ozbek and Coruh, 2012). This chalcid parasitic wasp was reared from mines of *T. absoluta* and it may be primary and secondary parasitoid of this pest (Doganlar and Yigit, 2011). The wasp genus *Haltichella* currently includes about 20 species parasitizing Lepidoptera pupae in the Neotropics (Hanson and Gauld, 1995). *Hockeria unicolor* (Walker) is common and widely distributed in the Palaearctic region from Canary Islands to Central Asia (Baez and Askew, 1999). It is known as a pupal parasitoid of microlepidoptera of the families Tortricidae, Cosmopterigidae and Pyralidae (Blasco-Zumeta, 2000) but it was reared from larvae in mines of *T. absoluta* on tomato (Doganlar and Yigit, 2011) and observed attacking larvae of this pest (Marchiori et al., 2003b).

The **Torymidae** are a worldwide family of wasps (order: Hymenoptera) containing over 960 species in about 70 genera (Grissell, 1995). Torymines are diverse biologically but most are ectoparasitic upon larvae in galls formed by gall-forming insects, as well as Hymenoptera and Diptera and a few families of Coleoptera and Lepidoptera (Noyes, 2008). Members of the genus *Ecdamua* are reported to be parasitic on aculeate Hymenoptera nesting in holed dead wood (Boucek, 1988). So far six species, including *Ecdamua cadenati* (Risbec), are reported from different parts of the world (Ahmad et al., 2012) and four parasitoids were observed on *T. absoluta* in Kassala State, Sudan among which was E. cadenati (Mahmoud, 2013).

The **Pteromalidae** are a very large family (order Hymenoptera) of cosmopolitan small parasitic wasps which involves over 3506 species in 587 genera worldwide (Sureshan and Narendran, 2003). They are mostly primary parasitoids, but some are hyperparasitic; some are ectoparasitoids, whereas others are endoparasitoids. Pteromalids have considerable importance for the biological control of Lepidoptera, Coleoptera, synanthropic Diptera and Coccidae (Homoptera) (Legner, 1995; Kaydan et al., 2006). Species of the genus *Halticoptera* are known as parasitoids of mining Diptera associated with herbaceous plants or ferns (Mitroiu, 2005). The pteromalid *Halticoptera aenea* (Walker) was recorded as an endoparasitic wasp of *T. absoluta* (Giorgini et al., 2012; Öztemiz, 2012; Zappala et al., 2012a). Another pteromalid wasp, Pteromalus intermedius (Walker), was collected from the same pest and may be used to control it (Doganlar and Yigit, 2011; Öztemiz, 2012).

The **Ichneumonidae** (order Hymenoptera) is one of the most species rich families of all organisms with more than 60000 species in the world. Ichneumon wasps are important parasitoids of other insects. Common hosts are larvae and pupae of Coleoptera, Hymenoptera, and Lepidoptera. They have been used successfully as biocontrol agents of pests in these orders (for detail, see Townes, 1961; Aubert, 1969; Carlson, 1979; Gauld, 1991; Gupta, 1991). Parasitism of several species in the genus *Diadegma* was reported on different lepidopterous hosts (Azidah et al., 2000; Hill and Foster, 2000, 2003; Idris and Grafius, 2001; Akol et al., 2002; Sathe and Bhosale, 2011). *Diadegma pulchripes* (Kokujev) is known as larval parasitoids of Lepidopterans (Cravedi, 1992). This ichneumonid wasp was described as a larval endoparasitoid on *T. absoluta* in South America (Desneux et al., 2010), Turkey (Öztemiz, 2012) and Mediterranean area (Zappala et al., 2012a**)**. Another species of this genus, *Diadegma ledicola* Horstmann, was recorded as an indigenous natural enemy in the Mediterranean area and has a potential role in reducing population of *T. absoluta* (Giorgini et al., 2012; Zappala et al., 2013). The ichneumonid parasitic wasp *Pristomerus* sp. was reared from larvae of the avocado fruit borer *Stenoma catenifer* (Lepidoptera: Elachistidae) in Guatemala (Hoddle and Hoddle, 2008) and was observed on *Gymnandrosoma aurantianum* (Lepidoptera: Tortricidae) in Costa Rica (Blanco-Metzler et al., 2009). This ichneumonid wasp was identified as a larval endoparasitoid on *T. absoluta* in South America (Desneux et al., 2010) and Turkey (Öztemiz, 2012). Another ichneumonid wasp, *Temelucha* sp., was recorded as a larval parasitoid of *Spodoptera exigua* (Lepidoptera: Noctuidae) in Sekinchan, Selangor, Malaysia (Azidah, 2007) and *L. botrana* in Orumieh vineyards in Iran (Shoukat, 2012). The latter wasp was identified as a larval endoparasitoid on *T. absoluta* in South America (Desneux et al., 2010) and Turkey (Öztemiz, 2012).

1.2.2. Diptera

Tachinidae is a large and rather variable family of true flies within order Diptera in the world (Crosskey, 1980) with more than 8200 known species and many more to be discovered (Cantrell and Crosskey, 1989). All tachinids are parasitoids of other arthropods, ranging from caterpillars, the most common hosts, to spiders and scorpions (Williams et al., 1990). The tachanids *Archytas* sp. *Elfia* sp. were recorded as a larval endoparasitoids of *T. absoluta* (Desneux et al., 2010; Öztemiz, 2012).

1.3. Larval/pupal parasitoids

1.3.1. Hymenoptera

The braconid wasps *B. didemie* (Doganlar and Yigit, 2011; Yiğit et al., 2011) and *B. osculator* (Giorgini et al., 2012; Zappala et al., 2012a) had been reported as larval/pupal parasitoids of *T. absoluta*. The wasp *Orgilus* sp. was recorded as larval/pupal parasitoid of *T. absoluta* (Melo and Campos, 2000). Another brachonid larval/pupal parasitoid, *P. dingus*, was assessed as a biocontrol agent for *T. absoluta* under laboratory conditions in Argentina (Maria et al., 2004, Luna et al., 2007). The eulophid wasp *Galeopsomya* sp. was recorded as a fortuitous parasitoid of the citrus leafminer, *Ph. citrella* (Rodrigues et al., 2003). It was observed as larval/pupal parasitoid on *T. absoluta* (Melo and Campos, 2000). The wasp *H. zilahisebisi* was previously mentioned as larval parasitoid on *T. absoluta*, it was observed also as as larval/pupal parasitoid on the same pest (Morley et al., 2010). In addition, *Elasmus* sp. was recorded as larval/pupal parasitoid for *T. absoluta* beside its parasitism as larval parasitoid on the same pest (Öztemiz, 2012). The ichneumonid wasp *Campoplex haywardi* Blanchard is a solitary internal parasite of larvae of the potato tuberworm, *Ph. operculella* (Wearn, 1971). *C. haywardi* was identified as a larval/pupal endoparasitoid on *T. absoluta* in South America (Desneux et al., 2010; Bloem and Spaltenstein, 2011**)** and Turkey (Öztemiz, 2012).

1.3.2. Diptera

In **Tachinidae**, *Archytas marmoratus* (Townsend) is a solitary larval-pupal parasitoid of numerous species of Noctuidae (Lepidoptera)(Ravlin and Stehr, 1984; Valicente, 1989; Silva et al., 1997; Dequech et al., 2004). It did not recorded as larval-pupal parasitoid of *T. absoluta* but *Archytas* sp. and *Elfia* sp. were recorded as larval endoparasitoid of this pest.

1.4. Pupal parasitoids

Little records are available in the literature for the pupal parasitoids of *T. absoluta* in spite of their regular role to surpass the pest population (Desneux et al., 2010). This may a signal to urgent need for futher research in future. However, the reported pupal parasitoids as biocontrol agents for *T. absoluta* systematically belong to order Hymenoptera. In addition to their role as larval parasitoids in the biological control of *T. absoluta*, the following braconid wasps hand been reported also as pupal parasitoids on the same pest: *B. lulensis* (Berta and Colomo, 2000; Marchiori et al., 2003a; Desneux et al., 2010), B. tutus (Berta and Colomo, 2000; Marchiori et al., 2003a; Desneux et al., 2010; Öztemiz, 2012) and *B. lucileae* (Miranda et al., 1998; Berta and Colomo, 2000; Marchiori et al., 2003a; Desneux et al., 2010; Öztemiz, 2012) In addition to their role as larval parasitoids in the biological control of *T. absoluta*, the ichneumonod wasps, *D. pulchripes* (Giorgini et al., 2012; Zappala et al., 2012a) and D. leicole (Bacci, 2006), had been reported also as pupal parasitoids on the same pest.

In **Chalcididae**, *Conura* (syn. *Spilochalcis*) is primarily a New World genus with probably over 1000 species in the Neotropics which are pupal parasitoids of Lepidoptera, Diptera, Coleoptera, and Hymenoptera (Hanson and Gauld, 1995). *Conura* sp. was recorded as a pupal parasitoid on or used to control *T. absoluta* (Melo and Campos, 2000; Marchiori et al., 2003a, 2007; Desneux et al., 2010; Öztemiz, 2012). The chalcidid wasps *Haltichella* spp. are mostly parasite of Microlepidoptera, some are hyperparasitoids of the family Braconidae and others are regarded as parasitoids of Diptera (Glossinidae) in Africa (Rajabi et al., 2011). The same chalcidid wasp was reported as pupal parasitoid on *T. absoluta* (Marchiori et al., 2003b). The chalcidid wasp *Spilochalcis* sp. was reported as a parasitoid attacking the sesame leafroller, *Antigastra catalaunalis* (Lepidoptera: Pyralidae) in Colombia (Hallman and Sanchez, 1982). This wasp was reported as pupal parasitoids on *T. absoluta* (Marchiori et al., 2003b). The greatest incidence of parasitism of the lesser cornstalk borer, *Elasmopalpus lignosellus* (Lepidoptera: Phycitidae), was found by the chalcidid wasp *Invreia* sp. in Oklahoma (USA) (Berberet et al., 1979). It was also reported as a parasitoid attacking honeydew moth, *Cryptoblabes gnidiella* (Lepidoptera: Pyralidae) in the Eastern Mediterranean Region (Öztürk and Ulusoy, 2011). This wasp was recorded as a pupal parasitoid on *T. absoluta* (Desneux et al., 2010;

Öztemiz, 2012). It may important to mention that Invreia sp. is treated as a synonym of *Psilochalcis* sp. (Biradar, 2010). As the chalcid wasp *B. secundaria* was aforementioned as larval parasitoid on *T. absoluta*, it was also observed as pupal parasitoid on the same pest (Öztemiz, 2012). Another chalcid wasp, *H. unicolor*, was reported as a pupal parasitoid on *T. absoluta* (Öztemiz, 2012) as previously discussed as a larval parasitoid on the same pest.

2. Parasitic mites against *T. absoluta*:

Pyemotidae mites are widespread species and have been reported as ectoparasites of a large number of arthropods, especially of insects. They are parasites of all developmental stages of holometabolous insects, especially forest insects and stored product insects (Guldali and Cobanoglu, 2011). Species of the genus *Pyemotes* (Acari: Actinedida: Pyemotidae) might be considered as potential tools in biological control programs. The insect hosts of the parasitic mite *Pyemotes ventricosus* (Newport) were described (Cross et al., 1975). More than 100 insect species are known as hosts of the mite *Pyemotes tritici* (Lagréze-Fossat and Montagné) among Coleoptera, Hymenoptera, Lepidoptera, Homoptera, Strepspitera and Diptera, but it is primarily associated with Coleoptera and Lepidoptera (Bruce and Wrensch, 1990; Oliveira et al., 2010). In most cases, it was found on rearing mass in laboratories and stored products, attacking larval stages of some lepidopteras and coleopterans as well as adults of some coleopterans (Hoschele and Tanigoshi, 1993; Oliveira and Matos, 2006; Semyanov, 2006; Oliveira et al., 2007). This mite can tightly attach to the host body and paralyze it, by injecting venom (toxins) (Tomalski et al., 1988). However, *Pyemotes* sp. or *P. tritici*, was observed attacking *T. absoluta* (Cunha et al., 2006; Oliveira et al., 2007; Desneux et al., 2010; Öztemiz, 2013).

3. An insight for the parasitoids as promising biocontrol agents against *T. absoluta* in different parts of the world:

The development of approaches to manage *T. absoluta* in European, North African and Middle East countries depends on several factors. Many works were initiated on its control and much still remains to be done (Guenaoui et al., 2013). Taking into consideration the parasitic insects and mites, as natural enemies and biocontrol agents, especially against *T. absoluta*, it is important to review herein the available recent works in different parts of the world, particularly the invaded European, North African and Middle East countries as well as the origin of this pest, South American countries.

3.1. European, North African and Middle East countries

Possible use of the egg parasitic wasps of *Trichogramma* genus, as biological control agents against *T. absoluta*, is currently considered in Europe (Polaszek et al., 2012; Urbaneja et al., 2012; Zappalà et al., 2012a). Chailleux et al. (2012) compared the efficiency of 29 *Trichogramma* species and strains in parasitizing *T. absoluta* eggs on tomatoes at three different scales. In respect to the larval parasitoids, a scientific basis for the inclusion of the parasitoid *B. nigricans* in *T. absoluta* management programs was provided in Afro-Eurasia (Biondi et al., 2013b). The larval parasitoids *N. artynes* and *N. tidius* are naturally occurring in the Mediterranean basin and they had been evaluated for suppressing the severe infestations of *T. absoluta* in southern Europe (Desneux et al., 2010). Recently, the suitability of different instars of *T. absoluta* as hosts for *N. artynes* was evaluated at three different temperature regimes (20, 25 and 30°C)(Calvo et al., 2013**)**. However, the biocontrol of *T. absoluta* by parasitoids in some important tomato-producing countries can be reviewed herein in some detail.

In **Spain**, suppression of *T. absoluta* infestations on the tomato plant can be given by parasites such as *Trichogramma* spp., *H. zilahisebessi*, *Necremnus* spp. and *Diadegma leicole* (Molla et al., 2008; Gabarra and Arno, 2010). The egg parasitoid *T. achaeae* had been identified as a candidate for biological control of *T. absoluta* in greenhouses of the southeast of Spain (Cabello et al., 2009a) and is currently being released in commercial tomato greenhouses (Arnó and Gabarra, 2010; Zimmermann et al., 2010). The biotic potential of *T. achaeae* and *T. urquijoi* for the control of *T. absoluta* was evaluated (Cabello et al., 2012b**)**. As a result, *T. achaeae* was found better at controlling pest populations than any other species. Prospecting for potential natural enemies of *T. absoluta* in the Canary Islands archipelago, new *Trichogramma* species, *T. achaeae, T. bourarachae, T. euproctidis* and *T. evanescens*, were identified (Polaszek et al., 2012). An alternative release method for *N. tenuis* and its combination with *N. artynes* in Spain was investigated (Calvo et al., 2012b). Also, *Stenomesius* spp. occur spontaneously in infested tomato plots in Spain, indicating that native parasitoids are adapting to the new host (Arnó and Gabarra, 2010).

In **Italy**, during the years following the first report of *T. absoluta*, several indigenous generalist parasitoids had been recorded on this new host. Among these, only a few have been identified as potential biological control agents (Giorgini et al., 2012; Zappala et al., 2012a; Biondi, 2013). During the period 2009-2010, nine species of indigenous parasitoids were collected from tomato leaves, infested by *T. absoluta*, in Liguria, Sardinia and Sicily. *N. artynes* and *N. tidius* were the most abundant species which appeared to be promising as biological control agent (Ferracini et al., 2012; Tavella et al., 2012). The parasitoid *D. phthorimaeae* proved to be a biocontrol agents against *T. absoluta* (Luna et al., 2011). *A. fuscipennis* was collected from larvae of *T. absoluta* infesting Solanum nigrum plants in Tuscany (Central Italy)(Loni et al., 2011). *B. nigricans* proved to be an ectoparasitoid of *T. absoluta* 3rd and 4th instar larvae (Zappala et al., 2012b).

In **France**, sixty-four new potential strains from 19 Trichogramma species originating from different regions of the world had been studied (Khanh et al., 2012**)**. During the seasons 2011 and 2012 in Southern France, eggs of *T. absoluta* were attacked by *T. achaeae* whereas the larvae were parasitized by four parasitoid species, *B. nigricans, N. formosa, S. japonicus* and *N. artynes* (Biondi et al., 2013a). As concluded by a research project of Wageningen UR Greenhouse Horticulture in The **Netherlands**, two ectoparasitic wasps, *E. inunctus* and *P. soemius* had been developed successfully on *T. absoluta* (Desneux et al., 2010). The suitability of different instars of *T. absoluta* as hosts for the parasitic wasp *N. artynes* was studied (Calvo et al., 2013). In **United Kingdom**, the egg parasitoid *T. achaeae* was found as an effective control agent for *T. absoluta*. In addition, two parasitoids, *N. artynes* and *H. zilahisebisi*, had been detected on *T. absoluta* larvae but it remains to be seen whether they have value as biological control agents (Morley et al., **2010**). The Palaearctic parasitoid *N. artynes* had been shown to attack *T. absoluta* in the **Belgian** fields, but its parasitism is generally low. A study was carried out to determine the impact of non-host resources on host-parasitoid interactions and the potential for using selective food resources in conservation biological control of *T. absoluta* (Balzan and Wäckers, 2013). Doganlar and Yigit (2011) studied the parasitoid complex of *T. absoluta* in Hatay (**Turkey**). In the greenhouse of the University, 9 parasitoid species from 4 families of Hymenoptera were obtained. Thereafter, several species of parasitoids had been reported as biological control agents such as *Trichogramma* species (Öztemiz, 2012).

In **Tunisia**, few experiments for biological control of *T. absoluta*, using the egg parasitoid wasp *T. cacoeciae*, were carried out (Abbes et al., 2012). In order to investigate the possible use of parasitoids to control *T. absoluta*, a survey of native *Trichogramma* species was conducted in oases of the South West of Tunisia and the locally collected strains of *T. bourarachae* were found promising biocontrol agents (Zouba et al., 2013). Also, a research was conducted to assess whether generalist indigenous parasitoids are adapting to *T. absoluta* in four Tunisian tomato-growing areas. Two ectoparasitoid species, *Bracon* sp. and *N. artynes*, had been found attacking and developing on *T. absoluta* while no egg and pupal parasitoids were found (Abbes and Chermiti, 2013). Very recently, Abbes et al. (2014) assessed whether generalist indigenous parasitoids are adapting to *T. absoluta*, as an exotic host in Tunisian tomato crops. Their results showed that two ectoparasitoid species were found attacking and developing on *T. absoluta*: *Bracon* sp. and *Necremnus* sp. nr *artynes*, whereas no egg or pupal parasitoids were found.

In **Algeria**, the parasitoids *N. artynes*, *Neochrysocharis* sp., *Sympiesis* sp., *D. isaea* and *N. artynes* were found the most frequent and most abundant on *T. absoluta* (Boualem et al., 2012**)**. Although the larval ectoparasitoid *D. phthorimaeae* was described as a parasitoid on *T. absoluta* in Algeria (Benmoussa et al., 2009), Guenaoui et al. (2013) never found it in their samples associated with this pest. In South-east Algeria, recent research explored the possibilities of the native antagonists (*N. artynes*, *Stenomesius* sp., *N. formosa* and *B. hebetor*) for controlling *T. absoluta* (Dahliz et al., 2013). In North-west Algeria, the list of the native enemies monitoring *T. absoluta* infestation in greenhouses was expanded to reach over 10 native species with three dominant eulophid species: *N. artynes*, *Stenomesius* sp. and *N. formosa* (Guenaoui et al., 2013).

In **Jordan**, Al-Jboory et al. (2012) carried out a study in order to survey the natural enemies associated with *T. absoluta* and recorded the parasitic wasp *B.* (*H.*) *concolorans* for the first time. In **Egypt**, three different species of the egg parasitoids *Trichogramma* had been evaluated for controlling *T. absoluta* in greenhouses in Fayoum Governorate. *T. evanescens* was not strongly effective on tomato plants but possibility to be used in an IPM program against this pest (Gaffar, 2012). Control methods for *T. absoluta* were carried in Baltiem district, Kafrel-Sheikh Governorate. *T. evanescens* was found important in combination with some other biocontrol agents (Khidr et al., 2013). In Kassala State, **Sudan**, a survey was conducted and revealed four effective parasitoids associated with *T. absoluta*: *B.* (*H.*) *concolorans, B.* (*H.*) *hebetor, E. cadenati* and *N. formosa* (Mahmoud, 2013). In **Saudi Arabia**, the invasive species *T. absoluta* was recorded for the first time in August 2010. The strategy for the management of this pest comprises different components among which is the egg parasitoid, *T. acheae* (Sharidi et al., 2011). In **Iran**, Farrokhi et al. (2011) reported that the egg parasitoids *Trichogramma* spp. and larval parasitoid *Necremnus* sp. contribute to control of *T. absoluta*.

3.2. South American countries

In South America, reports of multiple species of egg parasitoids, belonging to the families Encyrtidae (Ripa et al., 1995; Colomo et al., 2002), Eupelmidae (Oatman and Platner, 1989) and Trichogrammatidae (Colomo et al.,

2002) are available in the literature. The possible use of *Trichogramma* species as biological control agents of *T. absoluta* is currently considered in South America (Polaszek et al., 2012; Zappalà et al., 2012a) and Latin America (Faria et al., 2008). In addition, the parasitoid *P. dignus* was reported as a major enemy of *T. absoluta* in tomato crops in South American countries (Maria et al., 2004; Luna et al., 2007). However, the biocontrol of *T. absoluta* by egg-, larval-, larval/pupal- and pupal-parasitoids in some important tomato-producing countries can be reviewed herein in some detail.

In **Brazil**, the biological control of *T. absoluta* by different species of *Trichogramma* was documented (Haji, 2002; Parra and Zucchi, 2004; Faria et al., 2000, 2008; Pratissoli et al., 2005). Some authors (Pratissoli and Parra, 2000, 2001; Parra and Zucchi, 2004) pointed out that the actual success with *T. pretiosum* had been the result of rigorous agent selection. The biological aspects and the parasitism of six strains of this egg parasitoid, reared on eggs of *T. absoluta*, were studied in order to select those with best biological features and more aggressive to control the pest (Tissoli and Parra, 2001; Pratissoli et al., 2006). A recent study was carried out to select the most suitable *T. pretiosum* strain for the biological control of *T. absoluta* in tomato crops (Vasconcelos, 2013). The *T. absoluta* eggs as host of another *Trichogramma* species, *T. evanescens*, were evaluated aiming to use this indigenous species for biological control of this pest (Payer et al., 2012). In addition to *Trichogramma* spp., some of the abundant other parasitoids were *B. lucileae*, *Diadegma* sp., *Haltichella* sp., *Conura* sp. and *Diadegma* sp. (Melo and Campos, 2000; Marchiori et al., 2003a, b, 2004, 2007).

In **Argentina**, evaluation of native larval parasitoids as BC agents against *T. absoluta* was carried out (Luna, 2013a). The biological control of *T. absoluta* using different species of *Trichogramma* was reported (Riquelme and Botto, 2003; Tezze and Botto, 2004; Caceres, 2007). Inundative releases of *T. bactrae* on grown tomatoes, infested with *T. absoluta*, in greenhouses gave good control (Botto et al., 2009; Riquelme et al., 2006; Virgala and Botto, 2010). On the other hand, another trichogrammatid egg parasitoid, *T. nerudai*, is currently under evaluation for *T. absoluta* control (Caceres, 2007). In addition to Trichogammatidae, several parasitoids have been reported on *T. absoluta*, with *P. dingus* and *D. phthorimaeae* as the most commonly found in commercial tomato crops (Berta and Colomo, 2000; Sanchez et al., 2009; Savino et al., 2013). Biology of *P. dingus* was extensively studied (Maria et al., 2004; Luna et al., 2007; Sanchez et al., 2009). Its inoculative releases had been tested in greenhouses before *T. absoluta* reaches high population levels (Botto, 2011). For the larval stage of *T. absoluta*, *P. dignus* could be considered as biocontrol agents against *T. absoluta* by means of augmentative releases (for details, see Caceres, 2007; Sanchez et al., 2009; Luna et al., 2011). In connection with *D. phthorimaea*, a positive trait worthmentioning is its apparent specificity for *T. absoluta* (Colomo et al., 2002; Luna et al., 2010). Although *N. formosa* was reported as potentially important parasitoid of *T. absoluta* in Argentina (Luna et al., 2005), Luna et al. (2011) believed that they provided the first record of *N. formosa* parasitizing larvae of *T. absoluta* only in organic outdoor and protected tomato crops in Northern Buenos Aires Province. Recently, evaluation of different food sources to improve the larval ectoparasitoid *D. phtorimaeae* fitness had been carried out (Luna, 2013b).

In **Chile**, the biological control of *T. absoluta* using different species of *Trichogramma* was investigated (Estay and Bruna, 2002; Delbene, 2003). *T. minutum* was collected for use against *T. absoluta* (Klein Koch, 1977). *T. pretiosum* was introduced from some South American countries into Chile and released for controlling *T. absoluta* in different tomato production regions (Ripa et al., 1995; Lavandero et al., 2006). Two other parasitoids had been reported to cause considerable mortality in *T. absoluta* larvae, *Retisympiesis phthorimaea* (Rojas, 1981) and *D. phthormiaeae* (Larrain, 1986). In **Colombia**, biological control of *T. absoluta* using different species of the egg parasitoids *Trichogramma* was documented (Vallejo, 1999). *T. exiguum* has potential for use in integrated control programms on tomatoes and thus at least 50% of routine insecticide applications are unnecessary (Navarro, 1988). Its parasitism levels reached 9.8-28.6% in open-field tomato (Salas, 2001). A broad complex of larval parasitoids had been reported of which *A. gelechiidivoris* had received a particular attention (Vallejo, 1999; Bajonero et al., 2008; Riano, 2012). Experiences of implementation of the parasitoid *A. gelechiidivoris* in greenhouses in Colombia had been conducted (Cantor, 2013). Unfortunately, Tachinidae had not been considered as promising biocontrol agents against *T. absoluta* (Oatman and Platner, 1989; Colomo and Berta, 2006). In **Peru**, as early as 1965, *T. minutum* was collected for use against *T. absoluta* while in 1973 *T. pintoi* was shipped to the same country for control of this pest (Whu and Valdivieso, 1999). As part of classical biological control schemes against *T. absoluta* in **Paraguay**, *T. pretiosum* had been moved extensively from some South American countries (Benitez, 2000).

3.3. Parasitic mites against *T. absoluta*

Some species of Pyemotidae mites (Acari: Actinedida) may be considered a new alternative for the biological control of *T. absoluta*. However, the detection of parasitic mites, particularly *P. ventricosus*, on this pest in a mass rearing kept at the Integrated Pest Management Laboratory (Federal University of Viçosa, Brazil) in October 2001 was narrated (Cunha et al., 2006; Oliveira et al., 2007). The mite *P. tritici* was recorded attacking *T. absoluta* in some South American countries (Trivelli and Velásquez, 1985; Cunha et al., 2006; Oliveira et al., 2007) as well as some *Pyemotes* spp. had been recorded on *T. absoluta* in some Mediterranean countries (Desneux et al., 2010; Öztemiz, 2013). The caterpillars and adults of this pest were quickly paralyzed by the mite venom. *Pyemotes* sp. can be a new alternative for the biological control of *T. absoluta*. However, this possibility must be better understood before it could be recommended, because *Pyemotes* sp. could also cause dermatitis in the humans (Oliveira et al., 2007).

4. Parasitoids of *T. absoluta*: parasitism mechanisms and factors affecting their parasitic efficiency:

All species of *Bracon*, as idiobiont ectoparasitoids paralyze the host larva at oviposition and the host does not develop any further while the parasitoid larva feeds from the outside (Al-Jboory et al., 2012**)**. As an idiobiont species, also, the larval solitary ectoparasitoid *D. phthorimaeae* halts the host development after attacking it by the injection of venom. One of the positive traits is its apparent specificity for *T. absoluta*. Among the mechanisms described for the parasitic behavior of this parasitoid, punctures with the ovipositor and mouthparts and the construction of a feeding tube were mentioned (Colomo et al., 2002). As reported by some authors (Jervis and Kidd, 1986; Luna et al., 2010; Savino et al., 2012), *D. phthorimaeae* practices non-concurrent destructive host feeding, that is, the adult female consumes host haemolymph and tissues without ovipositing, causing the death of the host.

With regard to factors affecting the parasitic efficiency of *T. absoluta* parasitoids, most efficient natural enemies have to show a high attack rate and be able to find their host whatever its density high or low. As for example, the functional response of *P. dingus* was described in laboratory. Females detect and parasitize the host within a wide range of densities (Luna et al., 2007). Considering the egg parasitoids *Trichogramma* species in inundative releases, one of the factors influencing on their parasitic efficiencies is the distribution pattern within the crop and host plant (Saavedra et al., 1997), and if there is a preference for specific niches they must coincide with those of the host (Bigler et al., 1997). Faria et al. (2008) conducted a study to determine how *T. pretiosum* exploit the egg distribution of *T. absoluta* on the plant canopy, and the effect of plant morphology on parasitism in Brazil. The levels of *T. absoluta* oviposition and parasitism by *T. pretiosum* were higher on the upper third of the plant, decreasing downward along the plant canopy. In addition, the 2-tridecanone (2-TD) content in the tomato genotype has influence on the parasitism of *T. absoluta* eggs by *T. pretiosum* (Goncalves-Gervásio et al., 2000). The parasitism efficiency of the egg parasitoid *T. achaeae* depends upon the use of high quantities of parasitoids/release, the infestation level by *T. absoluta*, and upon the presence of other natural enemies on the crop (Frandon et al., 2010).

5) Interference or interaction between parasitoids of *T. absoluta* and some other natural enemies:

Taking into consideration the successful use of parasitoids as biocontrol agents for *T. absoluta*, it should be of great importance to investigate their interference, integration or competitiveness with some other biocontrol agents. Better understanding of these relationships among available natural enemies will facilitate optimal decisions on what to use and when to use them. Several works reported the promise of parasitoid/predator combination, under the laboratory or greenhouse conditions. Release of the egg parasitoid *T. achaeae* against *T. absoluta* appears to be particularly promising when used in combination with mirid predators (Cabello et al., 2009b; Desneux et al., 2010). In the Mediterranean region of Turkey, some of the recommended control measures of *T. absoluta* involve integration of the egg parasitoids, especially *T. pretiosum* and *T. achaeae*, with the mirid predators, *Nesidiocoris tenuis* and *Macrolophus caliginosus* (Doganlar and Yigit, 2011**)**. Almost similar results had been obtained for releasing of *T. evanescens* with *N. tenuis* together to decrease the numbers of *T. absoluta* eggs and larvae (Öztemiz, 2013). Desneux et al. (2010; 2011b) carried out a choice experiment and suggested the importance of integrating the mirid predator *Macrolophus pygmaeus* with the oophagous parasitoid *T. achaeae* for inundative biological control of *T. absoluta* in the greenhouse tomato crop. An alternative release method for *N. tenuis* in combination with the parasitoid *N. artynes* reduced the control costs of *T. absoluta* (Calvo et al., 2012a). To control *T. absoluta* in the South-East of France, Trottin-Caudal et al. (2012) studied the use of *M. pygmaeus* and *T. achaeae*, alone and in combination. The best results were obtained when the two beneficials were released in combination. Recently, Chailleux et al. (2013a,b) provided some contributions in the same aspect and recommended the combination use of *T. achaeae* with *M. pygmaeus* for effective control of *T. absoluta* under laboratory and greenhouse conditions.

Considering the integration of *T. pretiosum* with *Bacillus thuringiensis* applications in the greenhouse tomato in Brazil, this strategy had been proven as technically viable and economically efficient (Medeiros et al., 2009) instead of 87% parasitism of *T. absoluta* by *T. pretiosum* alone (Parra and Zucchi, 2004). *B. thuringiensis* and the *T. abosluta*-egg parasite *T. achaeae* can provide good control of *T. absoluta* in tomato greenhouses (Desneux et al., 2010; Molla et al., 2011). Furthermore, *B. thuringiensis* and *T. achaeae* have been shown to be effective against *T. absoluta* and could be a supplement to the mirid predator *N. tenuis* (Calvo et al., 2012a).

The interference or competitiveness between parasitoids of *T. absoluta* and each other has attracted the attention of few biological control researchers, especially in Argentina. The parasitoid *N. formosa* was found coexisting in most sites with the native parasitoid *D. phthorimaeae* in Northern Buenos Aires Province. When *N. formosa* was found at early season, the proportion of parasitism was much higher (92%) than that of *D. phthorimaeae*, but closer to equal rates (46%) in late crops. *N. formosa* could develop earlier during the cropping cycle because of its competitors, *D. phthorimaeae*, apparently finds better habitat conditions in late non-protected crops (Luna et al., 2010, 2011). Recently, some aspects of competence between the parasitoids *P. dingus* and *D. phthorimaeae* had been elucidated in the laboratory. The younger *D. phthorimaeae* females avoided to attack *T. absoluta* larvae previously parasitized by its competitor; meanwhile older ones could not help using parasitized hosts, and consequently succeeding over the endoparasitoid (Savino et al., 2013). Moreover, non-indigenous *Trichogramma* strains or species used in biocontrol strategies may compete with native *Trichogramma*. When developing a biological control program using *Trichogramma* wasps, preference should always be given to indigenous species already present in the same region (Herz et al., 2007; Zouba et al., 2013). In fact, a successful establishment of non-native species is theoretically related to their higher competitiveness compared to native species as well as to the reduced control by natural enemies. However, several research works on the conservation of indigenous parasitoids of *T. absoluta* will be discussed thereafter in the present review.

6. Side-effects of synthetic and botanical pesticides on parasitoids of *T. absoluta*:

As pointed out by several authors (Lietti et al., 2005; Desneux et al., 2007; Silvério et al., 2009; Lebdi-Grissa et al., 2010; Biondi et al., 2012, 2013c), the occurrence of *T. absoluta* at increasing population levels led growers to extensively use insecticides. These chemicals could cause many side-effects on natural enemies in tomato crops. Side-effects of some insecticides were evaluated in the laboratory to maximize compatibility of chemical and biological control methods. This will help minimize any negative impact on the natural enemies (Pineda et al., 2007; Yu, 2008; Wang and Tian, 2009). The available literature contains a huge number of papers on the assessment of side-effects of different pesticides, synthetic or botanical, on various species of insect parasitoids. Several worldwide efforts have been reviewed herein aiming to increasingly attract the attention of entomologists and research institutions for selective and safer pesticides in respect to the parasitoids of *T. absoluta*.

Side-effects of some insecticides, chemically synthetic or of plant origin, had been tested on several species of Trichogrammid egg parasitoids. Effects of several insecticides were verified on the immature stages of *T. pretiosum*. Phenthoate and cartap were harmful, lambda-cyalothrin was intermediate, tebufenozid and teflubenzuron were harmless to slightly harmful, respectively (Cônsoli et al., 1998). The side-effects of other insecticides were investigated on different developmental stages of the same egg parasitoid (Carvalho et al., 2003**)**. Botanically, the bioactivities of *Trichilia pallida* and *Azadirachta indica* (neem) extracts were evaluated on the same parasitoid (Goncalves-Gervásio, 2003). In Egypt, effects of Chlorpyrifos (Dursban), Fenvalerate (Sumicidin) and Carbosulfan (Marshal) were studied on the pre-imaginal stages of *T. cacoeciae* (Abdel-Rahman and El-Aziz, 2012). Regarding the side-effects of some botanicals on the same parasitoid, two formulated products of each of Azadirachtin and Quassin had been tested. The residues of Quassin formulations were harmless (Abdelgader and Hassan, 2012). The biological aspects and parasitism viability of *T. evanescens* stages were studied after treatment with herbicides (Glyphosate, Bromoxynil, Thiobencarb and Clodinafop-propargyl) (El-Sebai and El-Tawil, 2012). Recently, toxicities of seven classes of chemicals were investigated against the same parasitoid. Neonicotinoids, pyrethroids and IGRs were less hazardous (Wang et al., 2013). The side-effects of deltamethrin (Garcia et al., 2006) and lambda-cyhalothrin, as well as a fungicide (basic copper sulphate) (Garcia et al., 2009) were evaluated on *T. cordubensis*. The effects of lambda-cyhalothrin, cypermethrin, thiodicarb, profenophos, methoxyfenozide, and tebufenozide were investigated on *T. exiguum* (Suh et al., 2000). For Trichogramma platneri, oxamyl and imidacloprid caused 100% mortality 48 hours after spraying but selectivity of diflubenzuron, fenoxycarb and tebufenozide was recorded for this egg parasitoid (Brunner et al., 2001). The side-effects of the carbamic pesticide cartap and some products of plant origin were evaluated on adults and immatures of *T. pintoi* in Peru (Iannacone and Lamas, 2003a, b). The residual effect of triflumuron and chlorfenapyr was evaluated on *T. bactrae* in Argentina (Virgala et al., 2006).

Side-effects of insecticides, chemically synthetic or of plant origin, had been studied on parasitoids other than Trichogrammatidae. Adults of the parasitic microwasps *C. koehleri* and *D. gelechiidivoris* seemed to be sensitive to the carbamic pesticide cartap in Peru (Iannacone and Lamas, 2003a). The acute toxicity and sublethal effect of Azadirachtin and borax salt plus citrus essential oil had been assessed on the larval ectoparasitoid *B. nigricans* (Biondi et al., 2012). Moreover, the risks of 14 pesticides, commonly used in tomato crops, caused multiple sublethal effects, notably reductions in parasitism rate on *T. absoluta*, fertility, longevity and also a male-biased sex-ratio of the progeny (Biondi, 2013). An extended laboratory bioassay was conducted to evaluate the toxicity and the duration of harmful activity of some modern insecticides on the parasitoid *Chelonus inanitus* in greenhouse (Medina et al., 2012).

7. Conservation of indigenous natural parasitoids:

It is worth pointing out that conservation biological control (CBC) strategies that imply on the use of indigenous biological control agents could play a key role against invasive pests (Pons et al., 2011; Ragsdale et al., 2011). It is the practice of enhancing the efficacy of natural enemies' assemblages that already exist in the area through modification of the environment, such as biodiversity conservation, landscape aesthetics, provision of clean water, reduce soil water retention or soil erosion (Perdikis et al., 2011), or of existing pesticide practices (Eilenberg et al., 2001; Barbosa, 2003). In spite to this importance, CBC has long been a rather neglected form of biological control, but research in this field has increased markedly during the last decade (Gurr et al., 2004; Wilkinson and Landis, 2005; Wade et al., 2008). Recent scientific reviews have considered CBC as a component of habitat manipulation (Landis et al., 2000; Gurr et al., 2004) or have focused on a part of CBC, e.g., plant-provided food for natural enemies (For several considerations, see Wackers et al., 2005; Jonsson et al., 2008; Balzan and Moonen, 2012; Ghoneim, 2014).

With regard to successful use of the parasitoid *N. formosa*, as well as other parasitoid species, against *T. absoluta*, biological studies on them would establish a foundation for a CBC programs (Luna et al., 2011). Surveys were carried out in Catalonia (Spain) to study the native parasitoids of larvae (*N. artynes* and *H. zilahisebessi*) and eggs (*Trichogramma* sp.) of *T. absoluta*. Results available until now show that the conservation of native natural enemies may be one of the best strategies to achieve good control of this invasive pest (Gabarra et al., 2010**)**. Zappala et al. (2012a) identified the parasitoid complex of *T. absoluta* in Southern Italy and their survey highlighted that conservation of indigenous natural enemies, also by means of habitat management techniques, should be taken seriously into account when planning integrated management strategy of the tomato borer in the Mediterranean area. Because the natural enemies are able to learn (van Driesche and Bellows, 1996), their response to their host can be improved when they are reared sequential generations on a host (van Driesche and Bellows, 1996). This occurs *via* enhancing their skills in orientation, host finding, host detection and acceptance (Noldus et al., 1990).

In **conclusion**, parasitoids are a very important component of the natural enemy complex of *T. absoluta* and have been the most common type of natural enemies introduced for biological control of it. In this respect, several considerations should be kept in mind because the efficient parasitoids must show a high attack rate and be able to find their host, whatever its density high or low. The successful use of these parasitoids needs a good understanding of their biological characteristics, ecological requirements and characteristics of the agro-ecosystem. Also, it should be of great importance to investigate their interference, integration or competitiveness with some other biocontrol agents. The competitiveness between parasitoids of *T. absoluta* and each other, of native and non-native species, must be studied. Because parasitoids are able to learn, their skills in orientation, host finding, host detection and acceptance can be enhanced. Selective pesticides that can be successfully used to control *T. absoluta* without adverse side-effects on its parasitoids are highly required. Better understanding of these relationships among available parasitoids will facilitate optimal decisions on what to use and when to use them.

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