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Predatory insects and arachnids as potential biological control agents against the invasive tomato leafminer, *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae), in perspective and prospective

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ABSTRACT

Although the tomato leafminer *T. absoluta* is a native pest to South America, it invaded many countries in center and north Europe and North Africa. Moreover, it has become an economically important insect in the major tomato-producing countries because its larvae reduce tomato yield and cause great losses of the fruit quality. The use of predators, as biocontrol agents, is an important alternative to the chemical insecticides. The present article reviewed the record and feasible use of different predator species belonging to several insect orders and families, as well as some arachnid species. This review provided, also, an insight on the predator as potential biocontrol agents against *T. absoluta* in different parts of the world, especially the tomato producing countries. In addition, the integration between predators and some other biocontrol agents, and conservation of the indigenous natural predators in relation to *T. absoluta* had been discussed.

Keywords: Arachnida, Coleoptera, Dermaptera, Heteroptera, Hymenoptera, Neuroptera, Thysanoptera.

1. Introduction

The tomato leafminer, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), is an invasive pest, native to South America, where it is considered one of the most devastating pests of tomato *Solanum lycopersicum* L. (or *Lycopersicon esculentum* (Mill.) (Solanales: Solanaceae) in several parts of the world [1-3]. Although *T. absoluta* is a pest native to South America, the first detection of it in Europe was in late 2006 (Iberian Peninsula) [4, 5]. It has expanded very quickly in three years (2007-2009) to many countries in center and north Europe [6]. Moreover, it has become an economically important pest in the major tomato-producing countries in the Mediterranean Basin countries of Europe and North Africa [2, 7-9]. Generally, it spreads very quickly in many countries of the western Palearctic Region [10]. More recently, the pest was reported in several Middle East countries [11].

This pest causes a very high level of damage (quantity and quality) to tomato crops [6, 12, 13], particularly if no control measures are adopted [11]. Larvae reduce tomato yield and fruit quality losses of up to 80-100% by attacking leaves and flowers, burrowing stalks, apical buds, green and ripe fruits [14-16]. Tomato plants may be attacked at any developmental stage from seedlings to mature plants in greenhouses and in open fields. Beside tomato, *T. absoluta* is also able to attack and cause damage on different genera and species of the Solanaceae plants [17]. As control strategies for *T. absoluta* consist mainly of early detection through sexual pheromone traps [18, 19], cultural methods also may be important [20]. The primary *T. absoluta* management strategy in most native home, South America, or invaded European and northern African countries, is chemical control [21, 22]. However, pesticides are only partially successful because of the general endophytic behaviour of the larval instars and the rapid selection of resistant populations [21, 22-24]. However, the resistance development in this pest to chemicals had been reported by several authors [15, 21- 23, 25, 26]. For implementing environmentally safe strategies, several eco-sustainable control methods and integrated pest management (IPM) programs have been recently evaluated [27-31].

Biological control (BC), within an integrated pest management program, is a challenging but potentially very beneficial tactic to develop [32]. BC programs have been used against crop pest insects belonging to the orders Homoptera, Diptera, Hymenoptera, Coleoptera and Lepidoptera, among others [33]. BC agents (living antagonists-natural enemies: predators, parasitoids and pathogens) are considered as one possible solution of the *T. absoluta* crisis [2, 34]. This strategy offers a more sustainable and less expensive alternative to chemicals [35, 36]. As reported by several authors [37-39], the impact of opportunistic native natural enemies (fortuitous BC) on *T. absoluta* should be considered as one of the key factors for suppressing the population density of this pest. In his review, Urbaneja et al. [40] updated the available information on indigenous natural enemies in Mediterranean countries. In addition, natural enemies are able to learn. This ability allows them to improve their response to their host when they are reared sequential generations on a host [41].

Predators help to maintain a balance among organisms, by consuming prey, altering prey behavior and prey habitat selection [42]. Thus, predators may increase the biodiversity of communities by preventing a single species from becoming dominant [43]. Vertebrate predators, such as birds, lizards and small mammals, are not really introduced for the pest control but the insect species are known to have some effect on insect pests [41]. Unfortunately there is a problem in the use of predators since many of them are seen as generalists and therefore not seen as highly effective BC agents [44]. Although specialized natural enemies are considered as most promising in BC [45], the generalist predators may also be of major importance in pest suppression [46]. In addition, the generalist predators may be better suited than specialists in diverse environments indicating their potential in conservation biological control [47]. Although predators did not attract the attention of tomato growers in various South American countries infested with *T. absoluta* as the parasitoids, predators could be responsible for up to 79.4% larval mortality and egg predation amounts to 5% [37]. Therefore, the present review is primarily concerned with the reported works on predaceous insects and arachnids as natural enemies and potential biocontrol agents against *T. absoluta* allover the world. It is secondarily interested in some related aspects, such as side-effects of pesticides on these predators, integration between predators and some other BC agents, and conservation of indigenous natural predators**.**

2. Predacious insects against *Tuta absoluta*

The predacious insects, as natural enemies or BC agents, with special emphasis on *T. absoluta*, can be reviewed herein according to insect orders and families.

2.1. Heteroptera

Miridae is a large and diverse insect family in the order Heteroptera. They are globally important pests of crops such as alfalfa, apple, cocoa, cotton, sorghum, and tea. Some also are predators of crop pests and have been used successfully in BC [48, 49]. *Macrolophus* species is worldwide marketed since the 1990s as a BC agent. They are generalist zoophytophagous predatory bugs naturally present in Mediterranean area [50]. Examples include *Macrolophus caliginosus* (Wagner) and *Dicyphus hesperus* (Knight) that are generally available and widely used in protected crops in North America and Europe, respectively [51]. Other mirids have been integrated into conservation biological control programs in horticultural crops in Europe and elsewhere, including *Nesidiocoris* (=*Cyrtopeltis*) *tenuis* (Reuter) [52, 53].

In tomato crops, the predators *Macrolophus pygmaeus* Rambur and *M. caliginosus* have been reported as a junior synonym of *Macrolophus melanotoma* (Costa) [54]. The mirid *M. caliginosus* (=*M. pygmaeus*) is a highly polyphagous predatory bug [55] which has proven to be effective in controlling many insect pests of greenhouse vegetables [56, 57]. This mirid predator was observed on or used to biologically control *T. absoluta* [16, 15, 55-69].

The mirid bugs of genus *Dicyphus* include zoophytophagous species, some of which are well-known for their role in the control of several pests of horticultural crops. In particular, *Dicyphus errans* (Wolff) is the species usually found in horticultural crops of northwestern Italy, but other *Dicyphus* species have been observed elsewhere in the crops of the North Mediterranean Basin [70]. This mirid predator was observed on or used as a biocontrol agent against *T. absoluta* [2, 71]. In addition, each of *Dicyphus tamaninii* Wagner [63, 72], *Dicyphus marrocannus* Wagner [2, 15, 59- 61, 73, 74] and *D. hesperus* [72] were observed preying on eggs and young larvae of *T. absoluta* and can be used to control this pest.

The mirid bug *N. tenuis* is a polyphagous predator widely distributed in the Mediterranean region, where it has been used as an augmentative BC agent for several plant pests [75-77]. It can make significant contributions to the control of greenhouse pests such as whiteflies, leafminers, lepidopterans and spider mites [53, 78]. This predator effectively suppress populations of the tomato fruit borer *Helicoverpa armigera* (Lepidoptera: Noctuidae) [79]. The same predatory mirid was observed preying on eggs and young larvae of *T. absoluta* and can be used to control it [15, 16, 58-61, 68, 69, 80-87].

The mirid predator *Tupiocoris cucurbitaceus* (Spinola) attacks several crop and vegetable pests in different parts of the world. As for example, it is associated with whiteflies in tomato crops as a natural enemy [15, 88]. López et al. [89] evaluated some biological characteristics of this species. This mirid predator was observed on or used to control *T. absoluta* [90].

The mirid predator *Heterotoma meriopterum* (Scopoli) was found as an important factor regulating the filbert aphid, *Myzocallis coryli* (Homoptera: Aphididae), populations in the filbert orchards of Oregon (USA) [91]. It was also found as an aphidophagous predator in Belgium [92] and recorded among the predatory insects belonging to Heteroptera in different hazel groves in Piedmont (NW Italy) and in Sardinia Island [93]. The mirid predator *Heterotoma* sp. had been recorded on *T. absoluta* and can be used against this pest [2, 65].

The **Anthocoridae** are a family of bugs classified in order Heteroptera and commonly called 'minute pirate bugs' or 'flower bugs'. Pirate bugs prey on other small insects, spider mites and insect eggs. This family contains between 400 and 600 species distributed worldwide [94]. The genus *Orius* consists of omnivorous bugs feeding mostly on spider mites, thrips, *Bemisia tabaci* (Homoptera: Aleyrodidae) and their eggs, but will also feed on pollen and vascular sap [95]. The omnivorous predator *Orius insidiosus* (Say) is considered beneficial, as it feeds on small arthropod pests and their eggs. This predatory bug was recorded on *T. absoluta* and can be as a biocobnrol agent against it [2, 15, 96-98]. Another anthocorid predator, *Orius laevigatus* (Fieber), is an economically important BC agent of several small arthropod pests [99]. It was recorded on or used to control *T. absoluta* [87]. The predator *Orius albidipennis* was recorded from several parts in Europe, Africa and Asia [96, 100-103]. This predatory bug is used for BC of *T. absoluta* [84,100]. The anthocorid predacious bug *Xylocoris flavipes* (Reuter) appears to be a promising agent for population suppression of both Coleoptera and Lepidoptera in stored products, since they prey on most stages of many of these species [104]. The *Xylocoris* sp. was recorded on or used as an egg predator for *T. absoluta* [15, 37].

The **Berytidae** (stilt bugs) represent a small family of true bugs in order Heteroptera. Most of them are phytophagous. Some species are occasionally omnivorous and facultative carnivorous or saprophagous [105]. The stilt bug *Metacanthus tenellus* Stål is a predator with vary species of pests as preys in the tomato crop such as eggs and larvae of *T. absoluta* [106].

Nabidae (order Heteroptera) prey on a variety of small invertebrates, chiefly arthropods. The predaceous habit, together with the widespread occurrence of some species in a variety of ecosystems, particularly agro-ecosystems, has attracted the attention of entomologists [107, 108]. Multi-stage dynamic model for a prey-predator interaction was applied to the damsel bug *Nabis pseudoferus* Remane [109]. It has been described as an effective predator against aphids and lepidopteran eggs and larvae, although it can feed also on other preys. Preliminary results identified it as a candidate for BC of *T. absoluta* by preying on larvae [2, 15, 28, 110]. In addition, Cabello et al. [111] demonstrated that *N. pseudoferus* will feed on *T. absoluta* eggs.

The **Lygaeidae** (order Heteroptera) are known as true bugs. The family includes the insects commonly known as milkweed bugs, and also some of those known as seed bugs. The family includes about 60 genera in six subfamilies (for some details, see [112]). Bell and Whitcomb [113] reported that the predatory big-eyed seed bug *Geocoris punctipes* Say was found among the most abundant and important predators of bollworm eggs, aphids, plant bugs, and young larvae in Arkansas cotton fields (USA). Orhanides *et al*. [114] reported that *G. punctipes* was an effective predator of the pink bollworm, *Pectinophora gossypiella* (Lepidoptera; Gelechiidae), in southern California cotton fields (USA). Some biological and ecological aspects of *G. punctipes* had been studied [115, 116]. *G. punctipes* was reported as biocontrol agent against *T. absoluta* [98].

Pentatomidae are a family of insects (order Heteroptera) including some of the stink bugs and shield bugs. The majority are herbivorous and some are predaceous on other insects. Many species, whether primarily herbivorous or predaceous, are generalist feeders [117]. Biology and ecology of the pentatomid stink bug *Podisus nigrispinus* (Dallas) and its use to control defoliating lepidopterous larvae in *Eucalyptus* plantations in Brazil were discussed [118]. Other Biological and behavioural studies had been conducted by some authors [119, 120]. *P. nigrispinus* was recorded as a BC agent for *T. absoluta* [15, 29, 35, 37, 80, 81, 121-123].

Reduviidae is a large, cosmopolitan family of predatory insects. It includes assassin bugs, ambush bugs, wheel bugs and thread-legged bugs. There are about 7000 species altogether, making it one of the largest families in the Heteroptera. Assassin bugs are essential components of ecosystems, but also important in agriculture and medicine (for some details, see [124-126]). *Debilia* sp. is believed to be a potential predator of adult leaf-footed bug *Leptoglossus* sp. (Heteroptera: Coreidae) [127]. This reduviid predator was observed as a natural predator of *T. absoluta* [2, 15].

2.2. Hymenoptera:

Vespidae constitutes a large family (nearly 5,000 species) in the order Hymenoptera. It is considered a diverse and cosmopolitan family of wasps, including nearly all the known eusocial wasps and many solitary wasps. Many species are pollen vectors contributing to the pollination of several plants, being potential or even effective pollinators, while others are notable predators of insect pest species [128]. Predatory Vespidae are the most voracious predators which can harvest very large numbers of invertebrate preys [129]. Also, the social wasps are generalist predators and are important agents for natural BC of phytophagous insects on natural environments and agroecosystems [37, 130-134]. Predatory wasps are well adapted to control lepidopteran larvae in high population densities [135]. Predation behaviour of *T. absoluta* by vespid wasps had been described by Picanço *et al*. [136]. There is a relatively large body of literature on certain species of predaceous vespid wasps, in the genera *Polistes*, *Polybia*, *Brachygastra*, *Protonectarina* and *Synoeca*, as well as their promising role in the BC against several insect pests including *T. absoluta*.

The paper wasps *Polistes* are classified in a cosmopolitan genus. It is also the single largest genus within the family Vespidae, with over 300 recognized species and subspecies. Paper wasps feed on nectar, and insects, including lepidopterous caterpillars, flies, and beetle larvae [137]. Specialization on caterpillar preys makes *Polistes* suitable for augmentative BC of lepidopterous pests of field crops [138, 139]. With regard to the paper wasp *Polistes versicolor* (Olivier), it was reported as a natural enemy of the cassava hornworm (*Erinnyis ello*) (Lepidoptera: Sphingidae) [140] and the coffee-leaf-miner *Leucoptera coffeella* (Lepidoptera: Lyonetiidae) [141]. In a study, Prezoto *et al*. [132] found that 95% of prey caught by *P. versicolor* was lepidopteran larvae. Moreover, it is one of social wasps preying on larval forms of coleopterous and dipterous pests of agricultural and forest crops [142-144]. This paper wasp was recorded as predator on *T. absoluta* [2, 15]. In addition, the vespid wasps *Polistes melanosoma* (de Saussure) and *Polistes carnifex* (Fabricius) were recorded as biocontrol agents for *T. absoluta* [2, 15].

Another paper wasp, *Polybia scutellaris* (White), is a eusocial wasp in South America [145]. It hunts and stores a large number of prey insects from different orders in their nests [145]. It is one of predators of the coffee-leaf-miner *L. coffeella* found in Brazil [141]. Its role as a pollinator is interesting and its role as biocontrol agent for agricultural pests is possible [146]. *P. scutellaris* was recorded as a predator on *T. absoluta* [15, 136]. In addition, *Polybia fastidiosuscula* Saussure, *Polybia* (=*Protopolybia*) *exigua* (De Saussure) and *Polybia ignobilis* (Haliday) had been recorded as predators of *T. absoluta* and can be used to control this pest [2, 15, 136, 147].

The dark paper wasp *Brachygastra lecheguana* (Latreille) is one of predators of *L. coffeella* found in Brazil [141]. Adults of *B. lecheguana* had been exposed to some insecticides in order to study its affected efficiency [147, 148]. The vespid wasp *B. lecheguana* was recorded preying on *T. absoluta* [15, 136, 148].

Morphological and physiological variation between queens and workers of the predacious social wasp *Protonectarina sylveirae* (Saussure) had been investigated [149]. The selectivity of 8 insecticides to *P. sylveirae*, among other vespid predators [147] and the toxicity of new pyrethroids [150] had been evaluated. This wasp was recorded as natural predator on *T. absoluta* [15, 136, 147, 148, 151].

As concluded by Prezoto and Braga [152], the social wasp *Synoeca cyanea* (Fabr.) has broad distribution throughout Brazil and had been considered as an interesting natural enemy of larvae of *Zaprinus indianus* (Diptera: Drosophilidae) as a dipteran pests of fruit crops. This wasp was recorded as a natural predator on *T. absoluta* in different parts of the world [2, 15, 136].

The **Formicidae** (family of ants) are social insects in order Hymenoptera. More than 12,500, out of an estimated total of 22,000 species, have been classified (for more details, see [153-155]).

Bownes [156] conducted a study on the use of ants for controlling crop pests and several studies have demonstrated that ants can be key generalist predators of crop pests in different parts of the world [157-162].

The tropical fire ant *Solenopsis geminata* (Fabricius) (=*Atta geminata* Fabricius) is native to the south-eastern coastal plain of Florida to Texas south through Central America to northern South America [163]. It is highly omnivorous feeder [164]. The predation of this fire ant on eggs of the apple snail *Pomacea canaliculata* (Gastropoda: Ampullaridae) was studied [165]. Way et al. [166] discussed the role of *S. geminate* in the BC of tropical upland rice pests. The same fire ant was observed as a pupal predator on *T. absoluta* [15, 167]. Another fire ant, *Solenopsis saevissima* (Smith), was recorded as potentially important predator of the sugarcane borer, *Diatraea saccharalis* (Lepidoptera: Crambidae), in sugarcane crops in Brazil [168]. The latter fire ant was recorded as a beneficial predator for control *T. absoluta* [2, 15, 169].

The ant *Pheidole megacephala* (Fabricius) is used as BC agent against the sweet-potato weevil *Cylas formicarius* (Coleoptera: Brentidae) [170, 171]. Larvae of the rice leaf-folder *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae) were found attacked by adults of the predatory ant *Pheidole* sp. [172]. *Pheidole* sp. was also recorded as a natural predator for the diamondback moth *Plutella xylostella* (Lepidoptera: Plutellidae) in Brazil [173] and for the sugarcane borer *D. saccharalis* populations [174, 175]. The same ant was reported as pupal natural predator suppressing the populations of *T. absoluta* [15, 167].

2.3. Dermaptera:

Family **Labiduridae**, whose members are known commonly as striped earwigs, is a relatively large family of earwigs in the suborder Forficulinae (order: Dermaptera). The family is mostly cosmopolitan (for some details, see [176, 177]). A number of laboratory studies, focusing on specific orchard pests, demonstrated earwig pest consumption ability of scale insects [177], aphids, [178], spider mites [179], and psyllids [180]. The earwigs are considered voracious predators because they have high ability to attack and feed on different preys, particularly eggs and immature stages of insects of the orders Lepidoptera, Hemiptera, Coleoptera and Diptera [181]. In contrast, some labidurids are considered as plant pests [182, 183].

The Indian earwig (or the tawny earwig) *Labidura riparia* Pallas is polyphagous predator [184]. It mainly preys on cutworms, caterpillars, small grubs, maggots, mealybugs, fleas and other insects [184]. In Brazil, this earwig was associated with commercial poultry ranches as BC agents [185]. In USA, it was recorded as a predator of pupal stage of lepidopterous pests in soybean fields [186], and was the most abundant predator in peanut fields [187]. In Germany, it is a predator of tomato pests [167]. In Egypt, it was recorded affecting the population densities of *Thrips tabaci* (Thysanoptera: Thripidae), *Empoasca* sp. (Hemiptera: Cicadellidae) and *Compylomma* sp. (Hemiptera: Miridae) in corn fields [188]; *B. tabaci* in cotton fields [189]; *Phthorimaea operculella* (Lepidoptera: Gelechiidae) in tomato and potato fields [190] and *Aphis craccivora* (Homoptera: Aphididae) in faba bean fields [191]. Some physiological aspects of *L. riparia*, such as consumption of prey and nature of carnivory, had been studied [192]. This Indian earwig was reported as a pupal predator for *T. absoluta* [15, 167].

Forficulidae is a family of earwigs, in the suborder Forficulinae (order: Dermaptera). It is the largest family of earwigs, with 250 species worldwide (for details, see [176, 193, 194]. The characterization of earwig, *Doru lineare* (Eschscholtz), as a predator of larvae of the fall army worm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), was studied [195, 196]. Zotti *et al*. [197] evaluated the survival of *D. lineare* adults after ingesting eggs of *S. frugiperda* contaminated with some insecticides. This earwig was recorded as a predator for controlling *T. absoluta* [2, 15].

2.4. Coleoptera:

Family **Coccinellidae** (order: Coleoptera) is a well-known beetle family, worldwide distributed and divided into six subfamilies [198]. Except for the mycophagous Coccinellinae and the phytophagous Epilachninae, all remaining coccinellids are predators of hemipteran insects from the suborder Sternorrhyncha (e.g. aphids, scales, psyllids and whiteflies), mites and eventually other insect larvae (for detail, see [199, 200]). Greater emphasis is needed on evaluation, predator specificity, understanding colonization of new environments, and assessment of community-level interactions to maximize the use of coccinellids in BC [201].

Some coccinellid species attracted the attention of BC specialists, particularly against *T. absoluta*. Herein, a number of the promising biocontrol coccinellids has been reviewed. Cardoso and Lázzar [202] examined the feasibility of use of the spotless ladybird *Cycloneda sanguinea* (Linnaeus) for the BC of the giant conifer aphids. *C. sanguinea* is a voracious predator of pests such as aphids, mealybugs, and eggs of Lepidoptera [203]. Nakasu *et al*. [204] reported *C. sanguinea* as one of the main predators of non-target pests in Brazilian cotton. This coccinellid predator was recorded as an egg predator for *T. absoluta* [15, 37, 205-207]. Another coccinellid, *Chilocorus nigritus* (Fabricius), is an important natural enemy against red scale *Aonidiella aurantii* (Hemiptera: Diaspididae) on citrus in southern Africa [208]. This coccinellid has been widely used for the BC of some pests such as the armored scale insects [209, 210]. The coccinellid predator *Chilocorus sp.* was observed attacking or used for controlling *T. absoluta* [211].

The spotted lady beetle *Coleomegilla maculata* De Geer is a natural enemy of several insect pests. It feeds on pollen and nectar to survive periods when prey is scarce [212]. *C. maculata* was found as among the most common predators for the soybean aphid, *Aphis glycines* (Homoptera: Aphididae) in North America [213]. Silva et al. [214] evaluated the development of *C. maculata* larvae fed on eggs of the Mediterranean flour moth *Ephestia* (=*Anagasta*) *kuehniella* (Lepidoptera: Pyralidae), eggs of *S. frugiperda* and nymphs of *Schizaphis graminum* (Hemiptera: Aphididae). Also, larvae of this lady beetle were reared on eggs of *E. kuehniella* in the laboratory studies [212]. This coccinellid predator had been observed preying on *T. absoluta* and may be used as a biocontrol agent against this pest [2, 15]. Considering the coccinellid predator *Eriopsis conexa* Germar, it was observed on *Artemisia absinthium* (Asteraceae) and *Foeniculum vulgare* (Apiaceae) plants, feeding on aphids [215]. It was reported as a natural predator on the aphids *Aphis* sp. and *Myzus persicae* (Homoptera: Aphididae) infesting Papaya tree in Brazil [160]. This coccinellid predator had been observed preying on *T. absoluta* [2, 15].

Carabidae is a large, cosmopolitan family of beetles (order: Coleoptera). They are commonly known as ground beetles including more than 40,000 species worldwide [216]. Carabids are generalist predators in crops and in natural habitats [217]. They are cited as being predators of aphids, lepidopteran larvae, slugs, and herbaceous plant seeds [218]. Also, many species of these beetles have a role in the natural BC for several lepidopteran pests in different crops [219, 220]. The ground beetle *Calosoma granulatum* (=*Calosoma alternans granulatum*) Perty was recorded as a predator of cotton leafworm *Anticarsia gemmatalis* (Lepidoptera: Noctuidae) in Bolivia [221]. Pegoraro and Foerster [222] evaluated the abundance and distribution of this predator and the determining conditions in Brazil. Larvae and adults of this predator may prey on relatively high numbers of the cotton leafworm *Alabama argillacea* (Lepidoptera: Noctuidae) pupae [219]. This ground beetle was observed as natural predator of *T. absoluta* [2, 15]. In addition, the carabids *Lebia concina* and *Selenophorus* sp. were observed as predators of *T. absoluta* [2, 15].

2.5. Neuroptera:

Chrysopidae (order: Neuroptera) is a large widespread family of insects comprising about 1,300-2,000 species in 85 genera. They are known as green lacewings. They feed on pollen, nectar and honeydew supplemented with mites, aphids and other small arthropods, and some, namely *Chrysopa*, are mainly predatory [223]. Therefore, their voracious predacious larvae are colloquially known as "aphid lions" or "aphid wolves". In several countries, millions of voracious Chrysopidae are reared for sale as BC agents of insect and mite pests in agriculture and gardens [224]. The predacious green lacewing *Chrysoperla externa* (Hagen) has a number of traits that make it amenable to mass-rearing. It. feeds on eggs and young larvae, and so can be utilized in BC programs [225-227]. The influence of adult food on the reproductive potential [228], the development [229, 230] and consumption capacity of *C. externa* on eggs and larvae of *S. frugiperda* and eggs of *E. kuehniella* [202] had been evaluated [231]. This lacewing was proved to be a good predator of *T. absoluta* larvae under laboratory conditions [15, 232]. The role of another Chrysopid species, *Chrysopa carnea* (Stephens), as a predator of the green peach aphid *Myzus persicae* (Homoptera: Aphididae) was demonstrated [233]. In Iraq, the biology of the predator *Chrysopa mutata*, fed either on the aphid *Hyalopterus pruni* (Homoptera: Aphididae) or the pseudococcid *Nipaecoccus vastator* (=*Nipaecoccus viridis*)(Homoptera: Coccidae) was studied in the laboratory [234]. The relationship between the predator *Chrysopa carnea* and preys (*Aphis faba*, *Aphis gossypii* and *Myzus persicae*, Homoptera: Aphididae) was studied in Egypt [235]. The third instar larvae of *C. carnea* have considerable potential for the control of *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae) [236]. The chrysopid predator, *Chrysopa* sp., was observed preying on *T. absoluta* [2, 15].

2.6. Thysanoptera:

Thrips (Order Thysanoptera) are tiny, slender insects with fringed wings. Thrips species feed on a large variety of plants and animals by puncturing them and sucking up the contents. A large number of thrips species are considered pests, because they feed on plants with commercial value. Some species of thrips feed on other insects or mites and are considered beneficial, while some feed on fungal spores or pollen. So far around 5,000 species have been described (for some details, see [237, 238]).

Thripidae (order: Thysanoptera) is a family of thrips with over 290 genera representing just over two thousand species. Several species are economically significant pests, some of them invasive [237, 239, 240]. The bionomics of *Scolothrips sexmaculatus* (Pergande), an insect predator of spider mites, was studied [241]. The predation efficiency of this predator on the two-spotted spider mite *Tetranychus urticae* Koch (Acari: Trombidiformes: Tetranychidae) was described [242]. The same thrips species was observed preying on *T. absoluta* [2, 15].

The **Phlaeothripidae** is the largest family in order Thysanoptera, with about 3550 species in 460 genera (for systematic details, see [243, 244]). A large number of species are considered pests, because they feed on plants with commercial value while some species feed on other insects or mites and are considered beneficial. Many species are fungivores living in the tropics and feed on fungal spores or pollen [237, 238, 245, 246]. Majority of species in the genus *Haplothrips* are European, breeding almost exclusively in flowers and many being host-specific. In contrast to the phytophagy of most members of the genus, the thrips *Haplothrips subtilissimus* (Haliday) is predator on other small arthropods [247]. Some *Haplothrips* species are known to prey on thrips [248]. For example, *Haplothrips victoriensis* Bagnall has been reported to be a natural enemy for the spider mite *T. urticae* [249]. In a mulberry field in Kagoshima, Japan, *Haplothrips brevitubus* (Karny) adults and larvae had been observed preying on the mulberry thrips, *Pseudodendrothrips mori* (Thysanoptera: Thripidae) [250]. However, some thrips species of the family Phlaeothripidae were observed preying on *T. absoluta* [37].

The **Aeolothripidae**, as a family of thrips, are particularly common in the holarctic region, although several occur in the drier parts of the subtropics. While they normally prey on other arthropods, many feed also on flowers [251]. *Franklinothrips* is a pantropical genus of ant-mimicking obligate predators [252]. Various members of the genus are considered to be, and are sometimes marketed as, useful BC agents against pest thrips [253]. *Franklinothrips vespiformis* Crawford has been marketed in Europe as a control agent against pests, such as the green-house thrips, *Heliothrips haemorrhoidalis* [254, 255]. It also feeds on mites, nymphs of a whitefly species and the larvae of an agromyzid fly [256]. Pizzol *et al.* [257] discussed the use of the predator *F. vespiformis* in an integrated pest management program. The same predator thrips was observed preying on *T. absoluta* [15].

3. Predacious arachnids against *T. absoluta*

3.1. Mites

Predatory mites in the family Phytoseiidae (Arachnida: Acari: Mesostigmata) have been successfully used in the BC of numerous agricultural pests worldwide. Many species of the genus *Amblyseius* are predatory mites feeding on other mites such as red spider mites, and also on thrips. Several species are popular as BC agents to control these pests [258]. In this regard, a population of the phytoseiid mite *Amblyseius swirskii* (Athias-Henriot) has been identified as a potential predator of the broad mite, *Polyphagotarsonemus latus* (Acari: Trombidiformes: Tarsonemidae), and is now a candidate for release against this pest on vegetable farms in Benin (Africa) [259, 260]. This mite was observed preying on eggs of *T. absoluta* in the Mediterranean Basin countries [15, 62, 74]. Wittmann and Leather [261] recorded the mite *Amblyseius cucumeris* Oudemans (= *Neoseiulus cucumeris*) as predator of the thrips *Frankliniella occidentalis*. Also, several studies had been carried out for use this predatory mite to control some species of thrips [262, 263]. Commercially available strains of live predatory mite *A. cucumeris* were investigated for predating on spider mite eggs and grain mite eggs [264, 265]. This predatory mite was observed attacking *T. absoluta* in the Mediterranean Basin countries [2, 74].

3.2. Spiders.

Conley [266] studied the predation versus resource limitation in survival of adult burrowing wolf spider *Geolycosa rafaelana* (Araneae: Lycosidae). Different studies had been conducted for the predation of wolf spiders on some insect pests such as three grassland grasshoppers in Nebraska (USA) [267]. Monzo *et al.* [268] revealed the potential use of DNA markers to track medfly predation by the wolf spider, *Pardosa cribata* Simon in citrus orchards in eastern Spain. Some wolf spiders had been recorded as pupal predators on *T. absoluta* [167]. Also, the wolf spider predator *Tanimlanmamis* sp. (Araneae: Lycosidae) was observed attacking *T. absoluta* in Turkey [15].

4. An insight for predators as promising biocontrol agents against *T. absoluta* in different parts of the world.

Taking into consideration the predators belonging to insect orders and arachnids, as natural enemies and biocontrol agents, especially against *T. absoluta*, it should be of great importance to compile some of the recently reported efforts in different parts of the world categorized in the most infested parts, the Mediterranean and European countries and South American countries.

4.1. Mediterranean and European countries.

In general, the mirid omnivorous predators *M. pygmaeus*, *N. tenuis* and *D. tamaninii* are considered to be among the principal natural enemies of pests on tomato crops in the Mediterranean region [2, 59, 73, 60, 61, 72, 74]. The naturally occurring populations of the mirid predators *Macrolophus* sp. and *Dicyphus* sp. can colonize tomato crops and keep the pest population below the damage threshold if chemical spreyings are reduced [269]. The mirid species *M. pygmaeus* is naturally present in Mediterranean area and used to control the populations of *T. absoluta* in protected tomato crops [270]. Beside it, the mirid predator *N. tenuis* can regulate *T. absoluta* populations, because it is able to prey efficiently on *T. absoluta* eggs [29]. However, the biocontrol of *T. absoluta* by predators in some important tomato-producing countries can be reviewed herein.

In **Spain**, *M. pygmaeus* and *N. tenuis* have already been tested under laboratory conditions to assess their suitability as *T. absoluta* egg and larval predators [61, 73]. According to these authors, in the tomato fields of Spain where the natural population of their predators were well established, the damage by *T. absoluta* was significantly lower than in the chemically treated fields. Field data indicated that pest incidence was lower when BC strategies based on the use of these two polyphagous mirid predators were applied instead of conventional chemical control [65, 271]. Molla et al. [60] showed that when *M. pygmaeus* and *N. tenuis* were established in tomato crop, they were able to reduce up to 75%-97% of leaflet infestations or 56% -100% of fruit infestations, respectively. In his study, Mollá [16] concluded that *N. tenuis* is a good BC against *T. absoluta* in tomato crops and its polyphagous behavior allows it to contribute in the control of other pests. It is possible to establish *N. tenuis* at the starting of the crop season and together a better and efficient control of *T. absoluta*, in tomato crops [272, 273]. A predator of the family Nabidae, *N. pseudoferus*, is also a native natural enemy usually found on tomato crops in Spain. An experimental work showed that its young nymphs can significantly reduce the numbers of *T. absoluta* eggs, indicating its potential as a promising candidate for the BC of this pest [110].

In **Italy** (Sardinia**)**, Nannini *et al.* [274] evaluated the efficacy of releasing of the predators *M. pygmaeus* or *N. tenuis* per m^2 for the control of *T. absoluta* infestations, under field conditions. Unfortunately, both predators failed to achieve the levels necessary for effective pest control due to the application of pesticides. The generalist mirid predator *D. errans* is usually used in the IPM tomato crop of northwestern Italy in tomato infested with *T. absoluta*. This mirid bug preyed mainly on eggs and first instar larvae [275]. In tomato plantations infested by *T. absoluta* during the period 2009-2010 in Piedmont, *D. errans* was largely found among nine species of indigenous natural enemies. It revealed to be an effective biocontrol agent preying mainly on eggs and first-instar larvae of *T. absoluta* [276]. This mired predator can be considered a promising potential candidate for controlling this pest, and further research is needed to assess its effectiveness under field conditions [71].

In **United Kingdom**, the results of BC measures for *T. absoluta* obtained by Morley et al. [62] can be summarized as follows. The mirid predator *N. tenuis* is a voracious predator feeding on eggs and larvae. Another mirid predator, *M. pygmaeus*, is closely related to *N. tenuis*. They feed on immature stages of *T. absoluta* and can provide some control of this pest in the absence of harmful insecticide residues. Also, the related species, *M. caliginosus*, has become established on many of UK tomato nurseries, and currently offers the best option for BC. However, according to a report from the UK, *N. tenuis* is problematic because it can attack host plants when prey are in short supply [277, 278].

A survey of natural enemies attacking *T. absoluta* was achieved by Biondi et al. [69] in Southern **France** during seasons 2011 and 2012. Three species of mirid predators, *M. pygmaeus, N. tenuis* and *Dicyphus* sp., were found preying on eggs and young larvae of the pest in both seasons. The obtained results represented the first step towards developing biological and IPM strategies against this pest in France.

In The **Netherlands**, some predators were found on the outdoor tomato plants. The mirid predator *D. errans* occurred regularly during summer and the mirid predator *Heterotoma* sp. was observed occasionally. Dutch growers will continue with the introduction of the predator *M. pygmaeus*, but they are always interested in new developments in BC of *T. absoluta* [2].

In **Turkey**, Öztemiz [15] reviewed several species of parasitoids and predators as BC agents against *T. absoluta*. He discussed the role of *N. tenuis* and *M. pygmaeus* in BC of this pest.

In **Jordan**, Al-Jboory *et al.* [84] conducted biweekly field visits (January-April 2011) to tomato fields (open and plastic houses) heavily infested with *T. absoluta*, in order to survey natural enemies associated with this pest. They recorded the occurrence of the Anthocorid predator *O. albidipennis* and mirid predator *N. tenuis*.

In **North Africa**, Boualem et al. [279] focused on biological study of *T. absoluta* and the natural mirid predator *N. tenuis* in natural conditions and in the laboratory in Mostaganem area (**Algeria**). In the vicinity of this area, Guenaoui *et al.* [63] recorded some natural enemies such as the mirids *N. tenuis*, *M. caliginosus* and *D. tamaninii* whose predation efficiency had been evaluated under the laboratory conditions. At the next year, Boualem *et al.* [66] revealed the presence of three mirid predatory species of *T. absoluta: N. tenuis*, *M. pygmaeus* (*caliginosus*) and *D. errans*. These results had been substantiated because a very recent research work explored the possibilities of the native antagonists, such as two mirid predators: *N. tenuis* and *M. caliginosus*, for the control of *T. absoluta* [68]. With regard to **Tunisia**, many attempts have been made to biologically control *T. absoluta* using the mirid predator *N. tenuis* in nurseries, greenhouses and open field tomato crops. Abbes *et al.* [83] carried out few experiments in BC, using the mirid predator *N. tenuis*. The factors of failure of this predator in a protected tomato crop were analyzed by Abbes and Chermiti [280]. Recently, Hamdi *et al*. [50] suggested a general schema to follow for a successful introduction of a natural enemy into an agro-ecosystem. They defined this schema based on the example of using the mirid predator *Macrolophus* sp. to control *T. absoluta*. They characterized the predation potential of *M. pygmaeus* under different temperatures to test its effectiveness and its adaptability to the climatic conditions of an introduction area in Tunisia. In **Egypt**, *N. tenuis* was recorded for the first time as associated with *T. absoluta* in tomato plantations in Giza, Qaluobia and Fayoum Governorates. Tabulated data were given on the predator sample collection from different localities in Egypt from May 2011 to October 2012 [77].

In connection with arachnids attacking *T. absoluta* or being used to control it in Mediterranean countries, *A. swirskii* and *A. cucumeris* are considered promising egg predators [2]. As summarized results of BC measures for *T. absoluta* in UK [62], the predatory mite, *A. swirskii*, has been seen feeding on the first instar larvae of *T. absoluta*.

4.2. South American countries.

Although a broad diversity of predators has been found in association with *T. absoluta* in tomato fields in various South American countries, some predator species have received attention as BC agents for this pest. In **Brazil**, anthocorid predator *Xylocoris* sp., *C. sanguinea* and members of Phlaeothripidae proved to be key predators of both egg and larval *T. absoluta* stages [37]. As pointed out by several authors [205-207], the occurrence of anthicid predator *Anthicus* sp., coccinellid predator *C. sanguinea*, Staphylinidae, *Orius* sp. and *Xylocoris* sp. and Formicidae were observed on *T. absoluta*. The predaceous wasp *P. sylveirae* is considered as one of key mortality factors of *T. absoluta* in the spring-summer [58] and caused 29.3-37.4% *T. absoluta* larval mortality [151]. After a few years, Picanço *et al*. [136] evaluated the importance of social vespid wasps as predators of *T. absoluta* larvae. They recorded the social vespid predators: *B. lecheguana, P. exigua, P. ignobilis, P. scutellaris, P. sylveirae, Polybia fastidiosuscula* and *S. cyanea*. The vespid predators *P. scutellaris* and *P. sylveirae* were the most abundant ones. The predatory pentatomid stinkbug *P. nigrispinus* has received vast scientific attention, with baseline research done on its life history (on *T. absoluta*) [35], its predatory behaviour [122], and its dispersal in the greenhouse environments [80]. The results suggested that *P. nigrispinus* is able to maintain its population preying only on *T. absoluta* caterpillars; however, the life table parameters determined individually showed that the pest produces more generations per year and faster population natural growth than the predator. It has the ability to survive on alternative prey, enabling it to maintain a presence in the tomato ecosystem until a primary pest species arrives [35]. In Brazil, also, the green lacewing, *C. externa*, proved to be a good predator of *T. absoluta* larvae under laboratory conditions [232]. Lins *et al*. [97] determined the predation capacity of *O. insidiosus* on eggs of *T. absoluta* under laboratory conditions. Bueno *et al*. [98] evaluated the predation efficacy of two hemipteran predators, *G. punctipes* and *O. insidiosus* as biocontrol agents against *T. absoluta*. Probst *et al*. [167] hint the importance of pupal predators of *T. absoluta* such as the labidurid *L. riparia*, the formicid *S. geminata, Pheidole* sp. and ground beetles. In **Venezuela**, the anthocorid, *O. insidiosus* was reported to be an important predator of *T. absoluta* eggs and larvae [281]. In **Chile**, Vargas [282] indicated that the nabid predator *Nabis* sp. and the vespid predator *Polistes* sp. are predators of *T. absoluta* in tomato fields. In **Argentina**, larvae of *T. absoluta* were being preyed on by a species of the coccinellid *Chilocorus* sp. [211]. The mirid predators *M. pygmaeus* and *N. tenuis* are attacking *T. absoluta*. An additional mirid, *T. cucurbitaceus*, has been recently evaluated as a potential BC agent against *T. absoluta* in Argentina [90].

With regard to arachnids attacking *T. absoluta* or being used to control it in some South American countries, Vargas [282] reported that spiders are predators of *T. absoluta* in tomato fields in Chile. In Brazil, Miranda et al. [37] indicated the presence of Araneidae attacking *T. absoluta*. Oliveira et al. [123] indicated that the mite *Pyemotes* sp. feeds on *T. absoluta* larvae, pupae and adults. They described its potential use in BC of the pest. Some wolf spiders were recorded among the important predators attacking *T. absoluta* [167].

5. Side-effects of pesticides on predators of *T. absoluta*:

Many indigenous species of native predators are successfully used within IPM programs resulting in high levels of control efficacy against *T. absoluta* [61]. Unfortunately, occurrence of this pest at increasing population levels led growers to extensively use insecticides, which could cause many side-effects on natural enemies in tomato crops [283-286]. Despite the importance of selective insecticide in preserving the natural BC of pests, little is known about insecticide selectivity in reference to predatory wasps [287]. Although some of the available insecticides used to control *T. absoluta* are not highly toxic to these predators [40, 288], evaluation of the side-effects of insecticides, widely used to control *T. absoluta*, attracted the increasing attention of numerous entomologists in different parts of the world. As examples, side-effects of some insecticides had been assessed on ground beetle *C. granulatum* [289]. Also, comparative side-effects of some synthetic insecticides and bioinsecticides had been evaluated on the green lacewing *C. externa* [290 -292].

Several worldwide efforts have been reviewed herein aiming to increase the enthusiasm for selecting safer or selective insecticides for the indigenous, or even introduced, predators. Two sulphur formulations, (dustable and wettable powder) are used in Mediterranean basin countries for controlling *T. absoluta* on tomato under greenhouse and open-field conditions, although its side-effects on *N. tenuis* should be taken into account [293]. In Spain, Arnó and Gabarra [5] evaluated the lethal and sublethal side-effects of three insecticides most widely used to control *T. absoluta* (azadirachtin, spinosad and indoxacarb) on the mirid predators *M. pygmaeus* and *N. tenuis*. In Italy, the dustable sulphur showed to be moderately harmful (as a fresh residue) for the generalist predator *N. tenuis* [285]. Also, Biondi et al. [286] assessed the risks of 14 pesticides (synthetic and biopesticides), commonly used in tomato crops, on the generalist predator *O. laevigatus*. Among the tested biopesticides only *Bacillus thuringiensis* Berliner (Bacillales: Bacillaceae) proved to be harmless; whereas spinosad, emamectin benzoate and metaflumizone were moderately harmful until 7 days after the treatment. Abamectin was the most noxious and persistent. In Italy, also, abamectin and oxamyl are usually used to control *T. absoluta*. After treatment with these pesticides, both *M. pygmaeus* and *N. tenuis* failed to achieve the levels necessary for effective pest control [274]. In Brazil, dose-response regression lines were estimated for adults of the vespid predator *B. lecheguana*, used against *T. absoluta*, after exposing to the insecticides abamectin, cartap, phentoate, and permethrin with or without 0.5%(v/v) mineral oil. Mineral oil increased selectivity in favor of the predator when in mixture with abamectin, permethrin, and cartap, but had a strong negative effect on phentoate selectivity [148]. Galvan et al. [147] assessed the selectivity of abamectin, acephate, carbaryl, deltamethrin, fenitrothion, fenpropathrin, methyl parathion and trichlorfon to the vespid predators *B. lecheguana, P. sylveirae* and *P. exigua* using insecticide concentrations corresponding to 50% and 100% of the current recommended rate for citrus caterpillars. The three predators were highly susceptible to both concentrations of fenitrothion, fenpropathrin and methyl parathion, and the highest concentration of trichlorfon. Very recently, Martinou *et al*. [294] evaluated the lethal effects of six insecticides and a fungicide on the predator *M. pygmaeus* nymphs exposed to the pesticides through three routes of exposure: direct, residual and oral. Chlorantraniliprole caused less than 25% mortality to *M. pygmaeus* and were classified as harmless. In contrast, thiacloprid and metaflumizone caused 100% and 80% mortality, respectively, and were classified as harmful. Indoxacarb resulted in close to 30% mortality to the predator, and was classified as slightly harmful, while the fungicide copper hydroxide caused 58% mortality and was rated as moderately harmful.

Concerning the side-effects of botanical extracts on predators of *T. absoluta*, Oliver and Bringas [106] evaluated the effects of neem and rotenone against the conventional synthetic pesticides managed by farmers in Peru, on the population variations of eggs, nymphs and adults of the stilt bug *M. tenellus* in the tomato crop. The results showed rotenone did not affect the developmental stages of *M. tenellus* and neem showed a slight effect while the high-test negative effect was observed after treatment with the conventional pesticides. Also, Iannacone and Lamas [295] tested the toxicological effects of extracts of two plants, Peruvian peppertree (*Schinus molle* L.) and lantana (*Lantana camara* L.) on the eggs, first stage larvae and pupae of the chrysopid predator *C. externa* under laboratory conditions in Perú. They discussed the possibility of using these botanicals in an IPM for *T. absoluta*.

6. Supplementation or integration between predators and some other biocontrol agents.

To test if the mirid predator *M. pygmaeus* would show preference between *T. absoluta* eggs and *Trichogramma achaeae*-parasitized (Hymenoptera: Trichogrammatidae) *T. absoluta* eggs, Desneux *et al*. [2, 296] carried out a choice experiment, and then tested if the predator would reduce the number of *T. achaeae*-parasitized *T. absoluta* eggs on whole tomato plants. Their findings suggested the importance of integrating the mirid predator *M. pygmaeus* presence in the greenhouse tomato crop when using oophagous parasitoids for inundative BC of *T. absoluta*. Also, it was found that the best BC of *T. absoluta* was obtained when *M. pygmaeus* and the parasitoid *T. achaeae* were released in combination [67, 297]. Considering another mirid bug, *N. tenuis*, an alternative release method for it and its combination with the eulophid parasitoid *Necremnus artynes* (Walker) (Hymenoptera: Eulophidae) had been evaluated. It was demonstrated that this alternative release method (pre-plant application) increased the predation capacity of *N. tenuis* and reduced control costs [298].

On the other hand, the integration of the bacterium *B. thuringiensis* treatments with the release or conservation of some mirid predators may provide a safe strategy to manage *T. absoluta* because *B. thuringiensis* targets larvae and mirids preferentially prey on *T. absoluta* eggs. Therefore, Molla *et al*. [29] hypothesized that *B. thuringiensis* treatments applied immediately after the initial detection of *T. absoluta* on plants did not interfere with mirid establishment in the crop since *T. absoluta* eggs were available. Afterwards, treatments with *B. thuringiensis* could be terminated, allowing the mirid predator *N. tenuis* alone to control the pest. Calvo *et al*. [298] developed an early release system for *N. tenuis* aiming to provide a good control of *T. absoluta* in tomato in Spain. *B. thuringiensis* and the parasitic insect *T. achaeae* had been shown to be effective against *T. absoluta* and could be a supplement to the predator *N. tenuis*.

7. Conservation of indigenous natural predators.

Conservation biological control (CBC) 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 [72], or of existing pesticide practices [299, 300]. In spite to this importance, CBC has long been a rather neglected form of BC, but research in this field has increased markedly during the last decade [301-303]. Recent scientific reviews have considered CBC as a component of habitat manipulation [301, 304] or have focused on a part of CBC, e.g., plant-provided food for natural enemies [305]. Several considerations had been discussed [306, 307]. For some details, wild or cultivated flowering plants, including weeds, in or around the field, can increase the diversity of habitats and provide shelter, suitable microclimate and alternative food sources for the natural enemies and can significantly increase the residency times and thus enhance the efficacy of these biocontrol agents [304, 308]. Among natural enemies, the feeding habits of predators largely influence their ecological identities and consequently their effectiveness in BC. For example, omnivorous heteropterous predators can utilize food of different trophic levels (i.e., animal and plant food). Phytophagy constitutes a common trait which can support at an intermediate or low rate the development and reproduction of these omnivorous predators. Its effect in predators' performance is largely determined by the host plant species. Generally, plant feeding may enable them to remain on the crop during periods when their prey is scarce (for details, see: [72, 309,310]).

It is well known that *T. absoluta* is a dangerous pest in a wide range of pests infesting tomatoes [2, 6, 15, 16]. Despite the diverse pest complex [311], their major natural enemies' assemblage is largely constituted by few predatory omnivorous mirid species. In the Mediterranean region, *M. pygmaeus*, *N. tenuis*, *D. tamaninii* and *D. errans* and in the North America, the mirid predator *D. hesperus* are considered to be among the principal natural enemies of pests on tomatoes [312-314]. Mirids are polyphagous, feeding on almost the entire spectrum of tomato pests. These mirid predators show phytophagous habits that support their development or reproduction to a variable rate depending on the plant substrate [52, 312, 315].

Alomar *et al*. [316] and Castañé *et al*. [317] showed that the colonization of tomato crops by native predators was higher in fields surrounded by complex agro-environments. Similarly, the environmental complexity may substantially influence the abundance of *M. pygmaeus* and *D. errans* in tomato greenhouses [70]. Further developments in CBC should be directed to identify which non-crop host plants support high numbers of these predators early in the season [318]. For example, *Solanum nigrum* (Solanaceae) is a major host plant for the predator *M. pygmaeus* in Greece [319]. Recent data have shown that *M. pygmaeus* can complete development on *S. nigrum* without prey and can also reproduce when infested by its main native aphid pest. Therefore, this plant should be evaluated in CBC systems, as a natural reservoir of *M. pygmaeus* for tomato crop colonization [320]. In greenhouse tomatoes, the use of alternative host plants has been evaluated as a means to introduce the mirid predator, *D. hesperus*. This predator was invariably found to be more common in greenhouses where the alternative host plant, *Verbascum thapsus* (Scrophulariaceae), had been introduced, providing also a refuge for the predator when prey on tomato was scarce. In tomato unheated greenhouses, Arnó *et al*. [321] showed that tobacco plants can serve as a refuge for the mirid predators during winter that may enhance the timely and efficient colonization of the next spring tomato crop. As a measure within the frame of CBC, it has been also suggested that the farmers could collect predators on crop plants at the end of the crop cycle or on major non-crop plants for subsequent release in greenhouses [319, 322, 323]. In addition, the tomato cultivars can affect the efficiency of natural enemies of *T. absoluta*. As reported by Cabello *et al*. [85], tomato cultivars were observed to influence the activity of natural enemies, mainly the predator *N. tenuis* in Spain. This may be because of differences in plant nutrients in different cultivars, which may affect the feeding of omnivorous insects. In contrast, cultivar effects on the egg-parasitoid *T. achaeae* were less apparent or possibly nonexistent. Nevertheless, there was an indirect effect in as much as *T. achaeae* was favored in cultivars not liked by the predator *N. tenuis*.

In **conclusion**, different predator species belonging to several insect orders, such as Heteroptera, Hymenoptera, Dermaptera, Coleoptera, Neuroptera and Thysanoptera, as well as some predator species belonging to a number of arachnid families, such as Phytoseiidae and Lycosidae, have been beneficial as biocontrol agents against *T. absoluta*. However, more research should be conducted for the integration between these predators and some other biocontrol agents. Also, conservation of the most efficient indigenous natural predators and selectivity of insecticides should be necessarily studied in detail.

8. Reference

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