

Study of Tomato Leaf Miner *Tuta absoluta* (Meyrick 1917) and its Potential Natural Enemies-12 Years after its Invasion of the Algerian Arid Environment

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ABSTRACT

The study concerns infestation and control of *Tuta absoluta* in the arid agricultural circles, case of Biskra (Southeastern Algeria). Within 2019-2020, a survey of this pest and its natural enemies was done on greenhouses tomato plants grown in rural and urban stations. In total, 501 beneficial arthropods were collected, 51.1% predators and 48.9% parasitoids, belonged to 2 classes, divided into 37 species from 19 families: Braconidae, Ichneumonidae, Miridae, Eulophidae, Anthocoridae, Chalcididae, Trichogrammatidae, Salticidae, Tachinidae, Anthicidae, Carabidae,

Coccinellidae, Geocoridae, Chrysopidae, Formicidae, Bethyridae, Scelionidae, Vespidae, Pteromalidae. The diversity of species in both locations is presented in table form; while, abundance, temporal variations, and correlation between infestation rates and natural enemies are represented by graphs. Obtained results represent the first step towards developing biological control strategies against this pest in southeastern Algeria. Furthermore, these results stress the need of conservation strategies of indigenous natural enemies to control the exotic pest species.

Keywords *Tuta absoluta*, Indigenous natural enemies, Biskra, Diversity, Temporal variations.

INTRODUCTION

The tomato pinworm, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is a major invasive pest of tomato and other Solanaceous crops (Cherif 2018). Originally from South America but it has spread to most Mediterranean regions and currently is in most African countries (Fiaboe *et al.* 2017). It's a very challenging pest to control. Effectiveness of chemical control is limited due to the insect's biology (the larvae make feeding galleries in the leaves, stems, apical buds, and fruits that protect them from chemicals) (Abdelmaksoud *et al.* 2016) as well as its high enzymatic capacity to detoxify pesticides (Ferracini *et al.* 2019). Consequently, alternatives to chemical control and particularly biological control have been attempted in several countries where many natural enemies of this pest have already been identified in its

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native ranges, and some of them (mostly parasitoids) are successfully used to manage this pest, especially the oophagous parasitoids of the Trichogrammatidae family which proved technically viable as biocontrol agents (up to 90% parasitism) in Africa (Mansour *et al.* 2018) and in Europe (El-Arnaouty *et al.* 2014). In addition to generalist predators of *Nesidiocoris tenuis* and *Macrolophus pygmaeus* which clearly showed its efficacy on 51% of eggs and 14% of first-instar larvae in laboratory conditions (Sylla *et al.* 2018), whereas egg and larval predator *Nabis pseudoferus* gave a high efficiency by 92% to 96% in Spanish greenhouses naturally or through artificial releases (Ferracini *et al.* 2019).

In Algeria, *T. absoluta* was reported for the first time in October 2008 (Boualem *et al.* 2012), and since then it has caused extensive damage to tomatoes in open fields and greenhouses in the country by larva-infested plants seedlings, debris including fruits left nearby and through the market trade selling fruits which are already infested (Ounis 2017). Numerous scientists have revealed the presence of its natural enemies in coastal areas of the country such Mostaganem, Mitidja, and Chlef of which three are predatory species and six are parasitoids (Boualem *et al.* 2012, Koudjil *et al.* 2014). Whereas, in the arid regions of Algeria, like Biskra oasis, the community of indigenous natural enemies of this pest remains poorly discovered, which obstructs the preparation of effective biocontrol approaches against it. Therefore, the first aim of this contribution is to conduct a general inventory on the natural enemies (parasitoids and predators) of *T. absoluta*, study their variations, their abundance also their biodiversity; And the second aim is to monitor *T. absoluta* infestation rates under greenhouse conditions in order to determine its most harmful stages and to suggest better guidelines and strategies for biological management of the leaf miner pests in the Biskra region.

MATERIALS AND METHODS

Study areas and tomato crops

The oasis of Biskra (34°51'00"N, 5°44'00"E) lies 470 km southeast of Algiers and belongs to the arid bioclimatic zone, which is characterized by a dry and

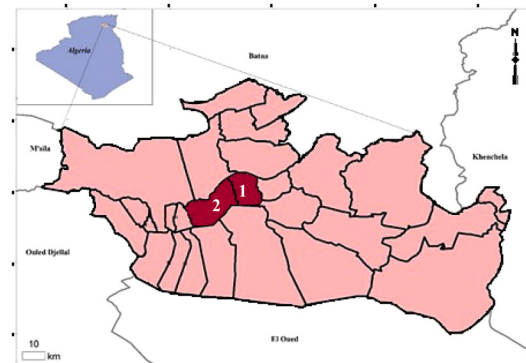


Fig. 1. Location of the study areas in Biskra province, (1) AlAlia, (2) Ain Ben Noui.

hot summer with a low rainfall winter. Grace to public funding for agriculture and an abundance of water, it has become the first national exporter of fresh vegetables in just a few years. The survey was conducted outside and inside 04 greenhouses of tomato crops (*Solanum lycopersicum*) (Fig. 1), as a principal host of *T. absoluta* in the region, spread in two different stations: AlAlia (34°50'43.9332"N, 5°44'53.5092"E), located in an urban area of 4 ha without any adjacent cultivation and Ain Ben Noui (ABN)(34°48'24.3"N, 5°39'16.3"E) situated in a rural area, characterized by the presence of palm trees, combined with cereal crops and quinoa trials in 21.5 ha. Note that the two stations have not undergone any chemical treatment.

Capture and identification of arthropods

Arthropods were collected throughout the crop cycle, every two weeks in 2019-2020. The species were sampled inside and outside the greenhouses with several methods, using yellow sticky traps, Barber pots, and yellow bottles that were installed at the height of plants, also the predators were sampled through active searching on tomato foliage and collected using an adapted aspirator. In parallel, to obtain the parasitoids and confirm their hosts, samples (larvae, pulp or eggs) that had already been parasitized (recognizable by their brown or black color) in our tomato greenhouses, were collected and placed in laboratory cages (diameter: 5cm, height: 3cm) at (23 ± 5°C and 58 ± 5% h; LD 16:8) conditions. All emerging parasitoids from each cage were monitored, captured and counted,

noting their favoured stage of the host; then they were individually stored in small bottles containing ethanol at 70°C prior to identification.

The identification of all species to the taxonomic level of family, genus and species was carried out using a binocular microscope in the laboratory of zoology in Algiers, based on adult morphology traits described in several keys of arthropods taxonomy, like Azidah *et al.* (2000), Poutouli *et al.* (2011), Chinery (2012) and Mignon *et al.* (2016).

Damage evaluation

To assess the damage caused by *T. absoluta* in tomato plantations, 200 leaves were randomly selected from the greenhouses and classified as damaged or healthy. This procedure was performed every 15-days from the time of the plantation and placement of traps to the uprooting time in July for each of the study greenhouses. The infestation rate was calculated using the values of leaves because they were attacked more than the fruits during their life cycle, by the formula: IR (%) = (Number of infected leaves/ number of total leaves (damaged/healthy)) *100.

Statistical analysis and diversity measurement

Analysis of variance (ANOVA) was performed to test differences between the seasonal means infestation

rates and natural enemies at the threshold ($P < 0.05$), then F-test and simple linear regression were made to determine the correlation between the number of natural enemies (dependent variables) and the infestation rate (independent variable) at ($P < 0.05$), using Statistica 6.1 Statsoft (SAS 2002).

In order to evaluate the abundance and the diversity of species in the study greenhouses, we analyzed the data using Statistica 6.1 Statsoft and SPSS (SPSS 2015). The numbers of the found species were exploited by some ecological indices such as Jaccard index ($I_c = N_c / (N_1 + N_2 - N_c)$) for gauging the similarity and diversity of sample stations, where “N1 and N2”: number of taxa present respectively at stations 1 and 2, “Nc”: number of common taxa to stations 1 and 2; Also, Simpson diversity index of ($D = \sum Ni(Ni-1)/N(N-1)$) for abundant species, and Shannon-Weaver diversity index ($H' = - \sum (Ni/N) \ln (Ni/N)$) to illustrate the complexity of populations, in which “Ni” is the number of individuals of species i, “N” is the total number of individuals; With equitability index ($E = H'/H'max$) which corresponds to the ratio of the specific diversity H' to the maximum diversity H'max, is expressed in bits, and Hill diversity index ($Hill = (1/D) / eH'$) for appreciating the ratio between the abundant species (Simpson) to the influence of rare species (Shannon), since “1/D” is the inverse of Simpson index, “eH'” is the exponential of the Shannon-Weaver index (Grall *et al.* 2005).

Table 1. List of indigenous natural enemies (parasitoids and predators) caught in Ain Ben Naoui (ABN) and AlAlia of Biskra region by month of appearance, December (Dec), January (Jan), February (Feb), March (Mar), April (Apr), May.

Species	Ecological role	Stage preferred	Known distribution	Month of appearance
<i>Archytas</i> sp.	Parasitoid	L	ABN	Dec-Jan-Mar
<i>Dacnusa sibirica</i>		L1–L2	ABN	Dec-Jan-Feb-Mar
<i>Cotesia</i> sp.		L	ABN	Feb-Mar-Apr
<i>Bracon</i> sp.		L3–L4	ABN	Feb-Mar-Apr-May
<i>Habrobracon hebetor</i>		L3–L4	ABN-AlAlia	Feb-Mar-Apr-May
<i>Dolichogenidea (Apanteles)</i> sp		L–P	ABN	Mar-Apr
<i>Apanteles gelechiidivoris</i>		L	ABN- AlAlia	Feb-Mar-Apr-May
<i>Pristomerus pallidus</i>		L	ABN-AlAlia	Mar-Apr
<i>Pristomerus</i> sp.		L	ABN	Mar-Apr-May
<i>Diadegma pulchripes</i>		L3–L4–P	ABN	Feb-May
<i>Diadegma ledicola</i>		L3–L4–P	ABN	May
<i>Diadegma mollipla</i>		P	ABN-AlAlia	Jan-Feb-Mar-Apr
<i>Campoplex haywardi</i>		L–P	ABN	Mar-Apr-May
<i>Goniozus nigrifemur</i>		L	ABN	Mar-Apr-May
<i>Brachymeria secundaria</i>		L3–L4	ABN	Dec-Jan-Feb

Table 1. Continued.

Species	Ecological role	Stage preferred	Known distribution	Month of appearance
<i>Haltichella spinola</i>		L3–L4	AlAlia	Feb
<i>Hockeria</i> sp.		L3–L4–P	ABN	Apr
<i>Telenomus remus</i>		L3–L4	ABN	Apr–May
<i>Stenomesus japonicus</i>		L2–L3	ABN	Jan–Mar–Apr–May
<i>Horismenus</i> sp.		P	ABN	Apr–May
<i>Necremnus tutae</i>		L	ABN–AlAlia	Mar–Apr–May
<i>Halticoptera aenea</i>		L	ABN	May
<i>Trichogramma achaeae</i>		E	ABN–AlAlia	Feb–Mar–Apr–May
<i>Trichogramma pretiosum</i>		E	ABN	Feb–Mar–Apr–May
<i>Salticidae</i> sp.	Predator	Not specified	ABN	Apr–May
<i>Selenophorus</i> sp.		L–P	ABN	Apr
<i>Chilocorus politus</i>		L	ABN	Apr
<i>Anthicus</i> sp.		L–P	AlAlia	Jan–Apr
<i>Nesidiocoris tenuis</i>		E–L1	ABN–AlAlia	Dec–Jan–Feb–Mar–Apr–May
<i>Macrolophus pygmaeus</i>		E–L1	ABN–AlAlia	Feb–Mar–Apr–May
<i>Deraeocoris punctulatus</i>		L	ABN	Apr–May
<i>Orius</i> sp.		L	ABN–AlAlia	Apr–May
<i>Lasiochilus</i> sp.		L3–L4	ABN	May
<i>Geocoris punctipes</i>		L	ABN	Mar–Apr–May
<i>Chrysoperla carnea</i>		E–L	ABN	Jan–Mar–May
<i>Tapinoma nigerrimum</i>		L	ABN–AlAlia	Dec–Jan–Feb–Mar–Apr–May
<i>Polistes carnifex</i>		L3–L4	ABN–AlAlia	Jan–Feb–Mar

RESULTS AND DISCUSSION

During the sampling period from December 2019 to May 2020, the different traps used in the greenhouses and the emerged species in the laboratory yielded a total of 501 beneficial arthropods against *T. absoluta*, 51.1% were predators and 48.9% were parasitoids, belonging to two classes (Arachnida and Insecta), divided into 37 species from 19 different families (Table 1).

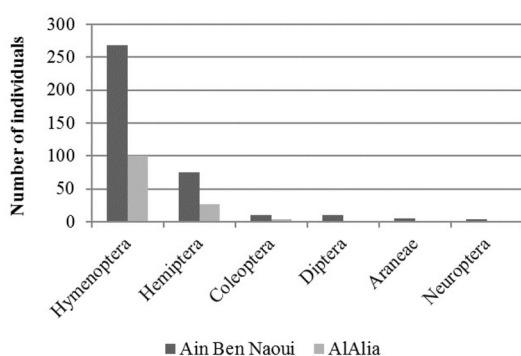


Fig. 2. Distribution of natural enemies orders of *T. absoluta* in the Biskra region.

Natural enemies of *T. absoluta* caught belonged to 6 orders, with a remarkable difference in species richness between the greenhouses located in rural station ABN and those located in urban station AlAlia (Fig. 2). The most numerous were representatives of the orders Hymenoptera (368 individuals, an average of 168 individuals between stations), Hemiptera (101 individuals, an average of 49), Coleoptera (13 individuals, an average of 7), Diptera (10 individuals, an average of 10), Araneae (5 individuals, an average of 5), Neuroptera (4 individuals, an average of 4), Where the orders of Diptera, Araneae and Neuroptera were totally absent in the urban station of AlAlia.

From December 2019 to May 2020, 18 families as part of the above orders were noted in tomato greenhouses of the rural station (ABN). The most numerous families were Braconidae (Ordre: Hymenoptera) (17.96%), Miridae (Hemiptera) (12.77%) and Ichneumonidae (Hymenoptera) (11.98%). Families Formicidae (Hymenoptera) (7.78%), Eulophidae (Hymenoptera) (4.39%), Vespidae (Hymenoptera) (4.19%), Trichogrammatidae (Hymenoptera) (3.99%) and Tachinidae (Diptera) (1.99%), Coccinellidae (Coleoptera) (1.39%), Geocoridae (Hemiptera) (1.19%),

Bethylidae (Hymenoptera) (1.19%), Anthocoridae (Hemiptera) (0.99%), Chalcididae (Hemiptera) (0.99%), Salticidae (Araneae) (0.99%), Chrysopidae (Neuroptera) (0.79%), Scelionidae (Hymenoptera) (0.79%), Carabidae (Coleoptera) (0.59%), Pteromalidae (Hymenoptera) (0.19%) of the total collected arthropods. In this period, 10 families were found in tomato greenhouses of the urban station (AlAlia). Families of Formicidae (13.77%), Miridae (4.79%), Braconidae (2.39%), Ichneumonidae (1.19%) and Trichogrammatidae (1.19%) were the most numerous, but Vespidae, Anthicidae (Coleoptera), Anthocoridae, Eulophidae and Chalcididae families occupied from 0.79% to 0.19% of the total collected arthropods.

Note that the number of families and individuals of *T. absoluta*'s natural enemies was higher in greenhouses located in the rural station (ABN) than those located in the urban station (AlAlia) at rates of 52.63% and 48.5%, respectively. At the same, their number was doubled outside the greenhouses in both stations, with a higher average outside the greenhouses of the rural station (ABN) (Fig. 3).

We found a clear difference in diversity between the greenhouses of two stations; Simpson (D), Shannon (H') and equitability diversity indexes (E) were higher in the greenhouses of the rural station (Ain Ben Noui), meaning that the species richness was more abundant and homogeneous in the greenhouses of this station than in the greenhouses located in the urban station (AlAlia), with a low number of similar species (IC) was present in both habitats, While there was an increase in (1-Hill) index due to the high current biodiversity in the greenhouses of the rural station compared to those of the urban station (Table 2).

Table 2. Biodiversity indexes of *T. absoluta*'s natural enemies in tomato greenhouses of Biskra.

Index	Greenhouses of Ain Ben Noui	Greenhouses of AlAlia
IC		0.29
D	0.05	0.14
H'	4.67	2.58
E	0.91	0.68
Hill	0.20	0.52
1- Hill	0.80	0.48

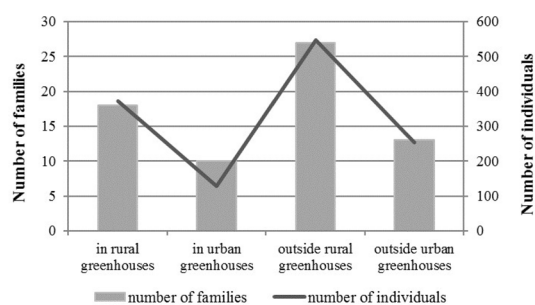


Fig. 3. Number of families and individuals of *T. absoluta*'s natural enemies in tomato agroecosystems of Biskra region.

At the beginning of the observations, the development of infestation rate recorded on tomato leaves during the winter period ($T = 18^{\circ}\text{C}$ - 22°C) was high in the greenhouses of both stations, and the difference between them wasn't significant according to statistical analysis ($F_{2,06} = 3.66$, $P = 0.628$); But from March until the end of the spring period, with a temperature reached to 40°C , the development of infestation rate peaked at maximum with a remarkable increase compared to the winter period in all the greenhouses, without any significant statistical analysis between the greenhouses of both stations ($F_{2,06} = 7.12$, $P = 0.34$). Also, the results in Fig. 4. explain that the infestation rate appears to be positively correlated with temperature as it was higher in the spring period than in the winter period in the greenhouses of two stations, where the statistical analysis was highly significant for the greenhouses of AlAlia ($F_{2,49} = 67.6$, $P < 0.0001$) and in those located in ABN ($F_{2,49} = 64.2$, $P < 0.0001$).

Figure 4. shows that the favorable thermal conditions are mostly responsible for the increase in natural enemies of *T. absoluta* in greenhouses of the two stations. The rate of natural enemies doubled during the spring with temperatures at 23°C - 35°C compared to the winter in temperatures at 8°C - 19°C in ABN greenhouses ($F_{2,179} = 22.875$, $P = 0.014$), but it was not significant under the greenhouses of AlAlia ($F_{2,179} = 2.417$, $P = 0.361$). But its development was stopped at 40°C compared to the infestation rate, which remained high even with the increase in temperatures. Moreover, the presence of natural enemies was low and sporadic compared to the infestation rate in all the greenhouses of both stations.

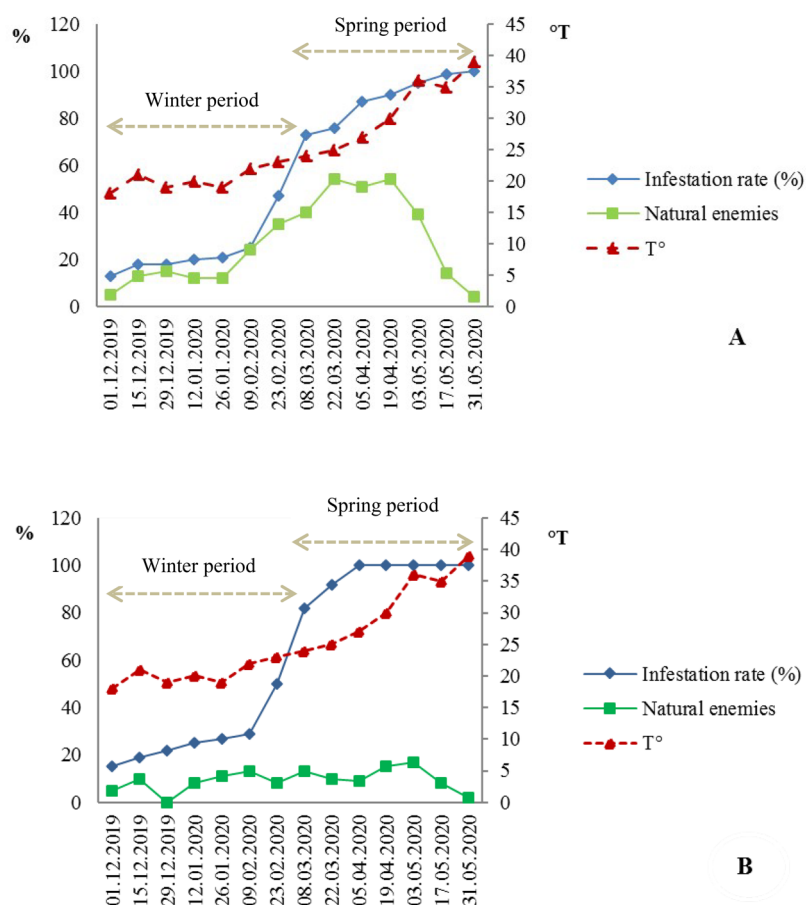


Fig. 4. Temporal variation of *T. absoluta* infestation rate and its natural enemies in ABN (A) and AlAlia (B) stations in function of temperature.

In general, the natural enemies experienced a temporal variation characterized by three remarkable peaks in the greenhouses of ABN: 29.12.2019 (19°C), 22.03.2020 (25°C), and 19.04.2020 (30°C), with four peaks of those located in Al Alia: 15.12.2019 (21°C), 09.02.2020 (22°C), 08.03.2020 (24°C) and 03.05.2020 (35°C). These peaks evolved in the ascending order of the infestation rate of *T. absoluta* in the greenhouses of the two stations respectively (Fig.4).

The analysis of variance and the F-test showed that the linear regression model is significant, with a weak coefficient of determination R^2 in the greenhouses of both stations, as these results proved the correlation of (6%-15%) between the number of *T.*

absoluta natural enemies for all the different levels of infestation rate and the time factor (evolution of the infestation of *T. absoluta* on the plants of tomato over time). Also, the statistical analysis revealed a linear association and significant difference between the imaginary population level of natural enemies and the infestation rate ($R^2A=0.1594$, $P=0.0001$, and $R^2B=0.0619$, $P=0.0001$) in the greenhouses of the rural station (Ain Ben Noui) and the urban station (AlAlia), respectively. This means that the presence of the host (*T. absoluta*) strongly stimulates the presence of its natural enemies with a positive combination (Fig.5).

This study has more catches of natural enemies of *T. absoluta* than those found by Boualem *et al.*

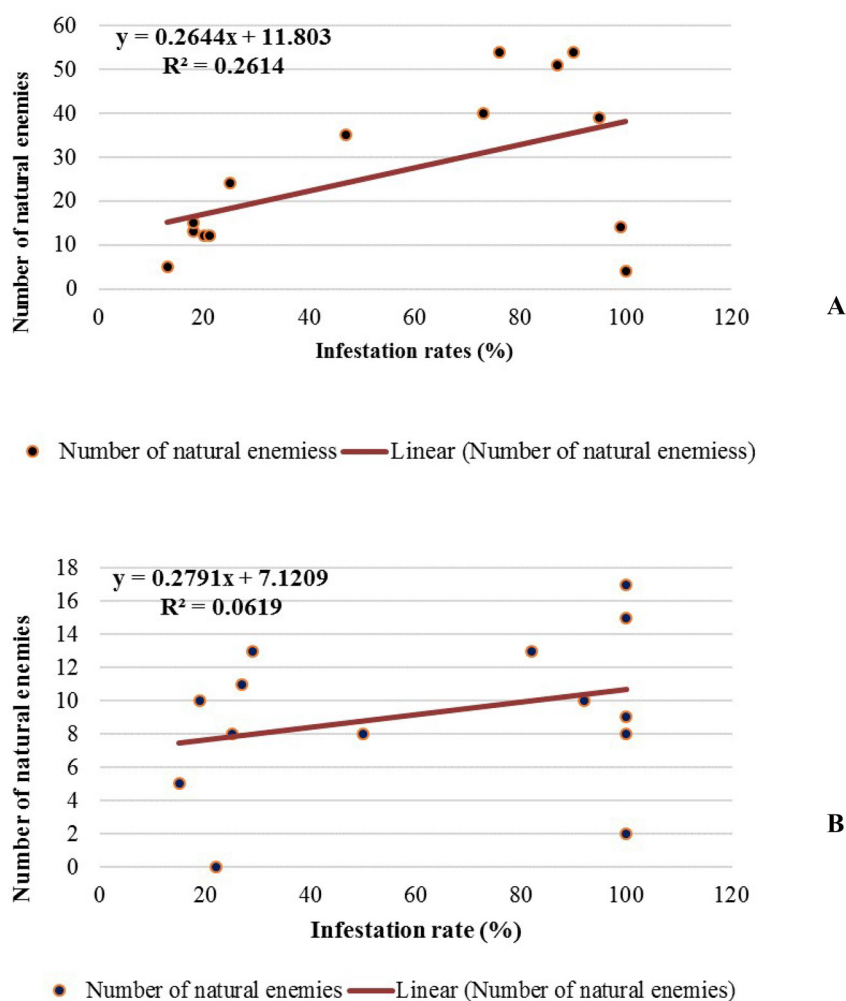


Fig. 5. Regressions between the number of natural enemies and the infestation rate in the greenhouses of the ABN (A) and AlAlia (B) stations.

(2012) in Mostaganem (Northwestern Algeria) and by Ounis (2017) in Biskra (Southeastern Algeria). These high statistics are due to the absence of chemical pesticides in our greenhouses, which have a wide range of effects, including on weeds that are food or habitat for some insect species (Balzan and Moonen 2014). Moreover, these findings exceed those of Sylla (2018) in the south region of Senegal due to their intense agricultural practices and small areas of semi-natural habitat around crops, in which Damien (2018) demonstrated that the richness of the plant cover provides food and shelter for a significant number of auxiliary species, as well as directly

influences the development of the trophic system of many arthropods which accelerates their dynamics and their expansion in the cultivated region. And following previous reports by Mansour *et al.* (2018) that emphasize the importance of assigning arthropods to different functional groups, all collected arthropods were categorized into functional groups:

> Parasitoids, Several hymenopteran species have been found, including the primary parasitoid of Braconidae family in the early stages of the host species, in a solitary or gregarious way (Mignon *et al.* 2016), where the endoparasitoid species *Doli-*

chogenidea (*Apanteles*) sp. Viereck, 1911 and *A. gelechiidivoris* Förster, 1862 have been identified as effective natural enemies of *T. absoluta* in its native range (Peruvian central highlands), especially on the first larvae (Aigbedion-Atalor *et al.* 2020), while the two species *Bracon sp* Fabricius, 1804 and *H.hebetor* Say, 1836 attack the mature larvae and study of the indigenous parasitoids in Biskra have indicated the presence of these species in the stations of Sidi Okba and Filiach (Ounis 2017), Mostaganem in the western coast of Algeria (Boualam *et al.* 2012), as well as in many African countries (Mansour *et al.* 2018). Also, the parasitism of braconid species *D. sibirica* Telenga 1934 has been confirmed on *T.absoluta* in Greece and Egypt (Abdelmaksoud *et al.* 2016), In addition, the endoparasitoid species *Cotesia sp.* Cameron, 1891 (Hymenoptera: Braconidae) gave a moderate rate of parasitism on *T. absoluta* in biological control programs of Africa (Fiaboe *et al.* 2017). Interestingly, six species of the hymenopteran Ichneumonidae family have been associated with pupae and late larvae in our study area. Sylla (2018) has revealed the presence of *P. pallidus* Kriechbaumer, 1884 and *Pristomerus sp.* Curtis, 1836 in Senegal, *D. pulchripes* Kokujev 1915, *D. ledicola* Horstmann, 1969, *D. mollipla* Holmgren, 1868 and *C. haywardi* Blanchard, 1947 have been identified in South Africa, Europe and the Mediterranean (Desneux *et al.* 2010, Ferracini *et al.* 2019), Also, the family Eulophidae includes the endoparasitoid species that we found attacking the pupae and mature larvae by the species *S. japonicus* Ashmead, 1904; *Horismenus sp.* Walker, 1843 and *N. tutae* Ribes and Bernardo, 2015 (Desneux *et al.* 2010), of which Boualem *et al.* (2012) previously indicated the abundance of *Necremnus sp.* Thomson, 1878 in Mostaganem. The chalcidid wasps of *Hockeria sp* Walker, 1834 were tested for their potential as biological control agents of *T.absoluta* in South Africa (Mansour *et al.* 2018), while the *B. secundaria* Ruschka, 1922 was recorded in Turkey on the larvae which gave a parasitism rate of 0.7% (Topakci and Keçeci 2017), as well, the *H. spinola*, 1811 parasitoid species were confirmed on larvae and pupae in Brazil (Uchoa-Fernandes *et al.* 1993). During this study, the abundance of *Archytas sp.* Jaenicke, 1867 (Diptera: Tachinidae) species was recorded, which was also found in South America (Desneux *et al.* 2010) and Turkey (Öztemiz 2012), as this species preferred to

parasitize the mature larvae of *T. absoluta* under laboratory conditions; the same results were recorded for parasitoid species *G. nigrifemur* Ashmead, 1894 (Hymenoptera: Bethyridae) (Moacyr *et al.* 2005), But, egg parasitoid species of *T. pretiosum* Riley, 1879 and *T. achaeae* Nagaraja and Nagarkatti, 1970 from (Hymenoptera: Trichogrammatidae) were found controlling the populations of this pest in tomato greenhouses of Brazil, Spain, Egypt (El-Arnaouty *et al.* 2014), in tomato open fields of Tunisian oasis (Cherif 2018) and in Mostaganem (Mansour *et al.* 2018). Notably, the parasitoid *T. remus* Nixon, 1937 (Hymenoptera: Scelionidae) was recorded in the late larvae of *T. absoluta* in Egypt (Abdelmaksoud *et al.* 2016), Iraq (Alrubeai 2017) and Brazil (De Abreu *et al.* 2015). While, it was observed that the endoparasitoids *H. aenea* Walker, 1833 (Hymenoptera: Pteromalidae) were emerging from the pupa and larvae of this pest in Italy, especially from the late larvae in the laboratory (Zappalà *et al.* 2013).

> Predators, A large abundance of *T. nigerrimum* Nylander, 1856 (Hymenoptera: Formicidae) has been recorded in tomato leaf mines, as a predator for *T.absoluta* larvae at all its stages (Moacyr *et al.* 2005, Zappalà *et al.* 2013). As well as social Vespidae species that are important bio-control agents in the agroecosystems, especially on Diptera, Lepidoptera, Hymenoptera and Hemiptera (Koudjil *et al.* 2014), whereas, the *P.carnifex* Fabricius, 1775 (Hymenoptera: Vespidae) predatory wasps were identified on the third and fourth stages of larvae in the laboratory. Hemipteran predators of Anthocorids, Geocorids, Mirids and Lasiochilids have also been recognized in their native areas as effective biocontrol agents for *T. absoluta* (Desneux *et al.* 2010). Species of Mirids (Hemiptera: Miridae) occur spontaneously in most Mediterranean countries, in which Ferracini *et al.* (2019) reported that *N.tenuis* Reuter, 1895 and *M.pygmaeus* Rambur, 1839 were highly effective in controlling eggs and first-instar larvae of *T. absoluta* larvae, although, *D. punctulatus* Fallén, 1807 (Heteroptera: Miridae) species supported the suppression of the immature stages in west Azarbaijan and Iran (Zarei *et al.* 2019). Interestingly, predatory species also included *Orius sp.* Wolff, 1811 (Hemiptera: Thripidae), *Lasiochilus sp.* Reuter, 1884 (Hemiptera: Anthocoridae) and *G. punctipes* Say, 1832 (Hemip-

tera: Geocoridae) (Zappalà *et al.* 2013), Whereas, Anthocorids belonging to the genus *Orius* have been found on *T. absoluta* larvae in Venezuela, Brazil and Jordan respectively (Zarei *et al.* 2019), Bacci (2018) studies on the genus *Lasiochilus* (Hemiptera: Thripidae) also confirmed its efficacy on late larvae. The generalist predator *Geocoris* sp. (Hemiptera: Geocoridae) significantly reduced populations of the tomato leafminer in the field crops and greenhouses (Koudjil *et al.* 2014). Further, the broad diversity was found in Coleoptera predators, where the *Sele-nophorus* sp. Dejean, 1831 (Coleoptera: Carabidae) species preferred larvae and pupae, also, the studies of Ghoneim (2014) confirmed the presence of *C. politus* (Coccinellidae) species on larvae, while, *Anthicus* sp. Paykull, 1798 (Coleoptera: Anthicidae) preferred the pupae and late larvae in the laboratory conditions; But the predatory species *C. carnea* Stephens, 1836 (Coleoptera: Chrysopidae) showed a high predation rate on eggs and first larvae (Ismoilov *et al.* 2020). In addition, many Salticidae sp. Blackwall, 1841 (Araneae: Salticidae) species were predominantly observed on *T. absoluta* larvae in Brazil (Desneaux *et al.* 2010).

The increase in natural and semi-natural areas in agricultural landscapes enhance the beneficial biological role of some insects, This is confirmed by our research, as the number and diversity of arthropods' taxa (orders, families, individuals) inside and outside the greenhouses of rural station surrounded by adjacent fields were greater than those in the urban station. According to Damien (2018), such places are ecological reserves that increase the prevalence of natural enemies; The predatory mirids like *Macrol-ophus* spp. Fieber, 1858 (Hemiptera: Miridae) as well as hymenopteran parasitoids attacking pests of tomato have been known to benefit from access to non-pest resources as pollen and extra-floral nectar (Portillo *et al.* 2012). A strong correlation between abundance of natural enemies like Coccinellidae Latreille, 1807 (Coleoptera), Syrphidae Latreille, 1802 (Diptera), Chrysopidae Schneider, 1851 (Neuroptera), Thom-isidae Sundevall, 1833 (Araneae) and availability of wildflower strips was reported in a study conducted in eight organic tomato fields in Italy (Balzan and Moonen 2014). Therefore, conservation of seminatural vegetation in preexisting field margins and sup-

plementing that with flowering strips is suggested as a valuable management strategy to support arthropod functional diversity in ephemeral crops like tomato (Damien 2018). Besides, the dynamics of individual populations or taxonomic structure of insects during the growing season can vary in agroecosystems depending on climate (Loehman *et al.* 2017). In response to this factor, the reproductive and survival rates of the insect community may change (Khaliq *et al.* 2014). In our study, the number of arthropod families and individuals fluctuated throughout the growing season, increasing during spring in temperatures above 20°C, and arthropod diversity indices changed accordingly. Also, Sharma (2014) showed that warming greenhouses enhance the diversity and activity of parasitoid insects, as well as generalist predators of insect communities, and that these factors directly affect the growth of many arthropods, improving diet richness. Lower temperatures have a direct impact on the availability of eggs and the growth rates of the host's larvae and pupae, which leads to decrease in the number of auxiliaries throughout the winter (Campos *et al.* 2020), while the right temperatures stimulate the laying of eggs and the abundance of larvae, which aids the growth of natural enemies due to the presence of the host; Further, it shortens the pupal stage and even the life cycle of the *T. absoluta*; which gave three to four generations per season in Biskra region, based on the number of peaks seen in Fig. 4. and confirmed by the results of Ounis (2017). Also, biotic and abiotic factors influence fertility, coupling efficacy, and even the mobility of larvae from each host plant resulting in increased infestation rate in greenhouses (Boualem *et al.* 2012). This study revealed significant differences between the *T. absoluta* population and its natural enemies, especially at the beginning of evolution, because it needs sufficient time to act and find hosts in order to prey on or disable them. For this, when pest populations are abundant in agricultural areas, most natural enemies don't respond quickly enough to limit the damage (Hajek and Eilenberg 2018). The specific richness of parasites and predators in a community is often influenced by indirect environmental dynamics such as competition and intraspecific hyperparasitism between species (Heimpel *et al.* 2017). These interactions may release herbivores from the pressure of the natural enemy and thus lead to disease outbreaks; In many agricultural ecosystems, natural

enemies alone are insufficient to control high pest populations, but the addition of chemical pesticides can supplement the agricultural protection program (Aigbedion-Atalor *et al.* 2020).

On the other hand, the effectiveness of predators and parasitoids in biological control depends on the synchronization of their life cycle with that of the pest (Van Lenteren *et al.* 2020), also they move and consume resources more quickly as temperatures rise until their thermal extremes specific to each species (Pernet *et al.* 2015). Based on the results presented in Fig. 4., we observed an exponential decrease in the abundance of natural enemies after 30°C in our greenhouses, in which Sharma (2014) and Pernet *et al.* (2015), previously reported that temperature clearly affects the metabolic activities of insects, drastically changing their behavior and physiological response to the trophic interactions for predation and parasitism. Similarly, Krid and Messati (2013) showed that predatory species against *T. absoluta*, notably, those of the Miridae family, were very active in the Ouargla Oasis between 15°C and 28°C, while Ounis (2017) confirmed the presence of a high abundance of *T. absoluta* parasitoids during the spring season in the oasis of Biskra. Also, the field data showed a striking pattern in the development of natural enemies, but their temporal abundance is almost absent during certain periods of the year, which means that seasonal influences play a significant role in driving the observed dynamics; Thus, understanding how multiple abiotic factors influence insect population densities, their conditions of initiation, as well as factors of persistence and adaptation in local environments is important for improving the efficacy of biocontrol agents and achieving an effective pest management program based on local parasites and predators (Damien 2018).

CONCLUSION

T. absoluta populations are well-established in the Biskra region and could potentially cause serious damage in protected areas of tomato cultivation; as the infestations continued to increase over time under suitable greenhouse conditions, particularly in spring. Due to its stability in this arid region for 12 years, this pest attracted 37 indigenous natural enemies

belonging to 19 different families. The parasitoids *D. sibirica*, *Bracon* sp. *H. hebetor* and *A. gelechiidivoris* of Braconidae; *T. achaea* and *T. pretiosum* of Trichogrammatidae; *D. mollipla*, *D. pulchripes* and *C. haywardi* of Ichneumonidae; *S. japonicus* and *N. tutae* of Eulophidae, with *N. tenuis* and *M. pygmaeus* predators of Miridae, which proved strong attachments to the host during the growing season, are among the most significant of these. Diversity indexes of all native biocontrol agents were more important during the spring period than during the winter period at the greenhouses located in diverse landscapes, since their adaptability to seasonal variation played a critical role in its density. But the global abundance and biodiversity of these agents were insufficient to control the pest, due to its feeble abundance and sporadic presence throughout the agricultural season compared to the host. It would be interesting to extend such studies to other localities in order to search for potential indigenous antagonists for this pest, also depth studies are necessary to know the life features of these different species.

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