

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

Evaluation of the effectiveness of *Dicyphus errans* (Wolff) as predator of *Tuta absoluta* (Meyrick)

This is the author's manuscript

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/139130> since 2016-01-13T15:41:29Z

Published version:

DOI:10.1016/j.biocontrol.2013.08.002

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)



UNIVERSITÀ DEGLI STUDI DI TORINO

This Accepted Author Manuscript (AAM) is copyrighted and published by Elsevier. It is posted here by agreement between Elsevier and the University of Turin. Changes resulting from the publishing process - such as editing, corrections, structural formatting, and other quality control mechanisms - may not be reflected in this version of the text. The definitive version of the text was subsequently published in *Biological control*, 67 (2), 246-252, November 2013, <http://dx.doi.org/10.1016/j.biocontrol.2013.08.002>.

You may download, copy and otherwise use the AAM for non-commercial purposes provided that your license is limited by the following restrictions:

- (1) You may use this AAM for non-commercial purposes only under the terms of the CC-BY-NC-ND license.
- (2) The integrity of the work and identification of the author, copyright owner, and publisher must be preserved in any copy.
- (3) You must attribute this AAM in the following format: Creative Commons BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/deed.en>), [<http://www.sciencedirect.com/science/article/pii/S1049964413001710>]

1 **Evaluation of the effectiveness of *Dicyphus errans* (Wolff) as predator of *Tuta absoluta***
2 **(Meyrick)**

3 B.L. Ingegno, C. Ferracini, D. Gallinotti, A. Alma, L. Tavella*

4 Dipartimento di Scienze Agrarie, Forestali e Alimentari (DISAFA), University of Torino, Via L. da
5 Vinci 44, 10095 Grugliasco (TO), Italy

6

7 *Corresponding author. E-mail: luciana.tavella@unito.it, phone number +39-011/6708533

8

9 ABSTRACT

10 Tomato crop in the Mediterranean Basin and in Europe has been recently affected by the exotic pest
11 *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), which is difficult to control due to its high
12 reproduction rate and potential to develop resistance to insecticides. In this paper, the suitability and
13 effectiveness of the predatory bug *Dicyphus errans* (Wolff) (Hemiptera: Miridae), an indigenous
14 species usually found in the IPM tomato crop of northwestern Italy, were evaluated on eggs and
15 larvae of *T. absoluta* under controlled conditions. This generalist predator could be an effective
16 biological control agent against the tomato borer. Both sexes of *D. errans* were proven to prey
17 actively on *T. absoluta* eggs and 1st-instar larvae. In particular, compared to males, females showed
18 a significantly higher egg consumption rate (11.0 ± 0.7 vs 8.6 ± 0.8 day⁻¹), and were also more
19 effective in preying on 1st-instar larvae (2.4 ± 0.5 vs 1.3 ± 0.3 day⁻¹). The mirid was able to develop
20 from egg to adulthood on tomato infested with eggs or with 1st-instar larvae of *T. absoluta*, even if a
21 high mortality of the predator was recorded in the latter case. Moreover, in olfactometer bioassays
22 predator adults proved to be attracted by tomato either infested or previously infested with tomato
23 borer larvae, independently of larval instars. *D. errans* can be considered a promising potential
24 candidate for controlling the pest, and further research is needed to assess its effectiveness under
25 field conditions.

26
27 Keywords: tomato borer, mirid bug, prey consumption, behavioural response, biological control

28

29 **1. Introduction**

30 Several species of Miridae Dicyphini (Hemiptera: Heteroptera) have received much interest for
31 their role in the biological control of many important pests in various vegetable crops (Malausa,
32 1989; Arzone et al., 1990; Tavella et al., 1997; Alomar et al., 2002; Castañé et al., 2004; Perdakis et
33 al., 2008). These generalist predators are characterized by zoophytophagous behaviour; thus, they
34 are strictly associated with the plant in addition to the prey (Alomar and Albajes, 1996; Sanchez et
35 al., 2004; Lykouressis et al., 2008; Ingegno et al., 2011). In the Mediterranean region, dicyphine
36 predatory bugs such as *Dicyphus cerastii* Wagner, *D. errans* (Wolff), *D. tamaninii* Wagner,
37 *Macrolophus costalis* Fieber, *M. pygmaeus* (Rambur), and *Nesidiocoris tenuis* (Reuter) have been
38 successfully established on horticultural crops, especially on tomato, *Solanum lycopersicum* L.
39 (Solanaceae), to control infestation by several pests such as aphids, leafminers, mites, thrips and
40 whiteflies (Cassis, 1984; Malausa and Trottin-Caudal, 1996; Carvalho and Mexia, 2000;
41 Lykouressis et al., 2000; Alomar et al., 2002; Arnó et al., 2003; Agustí and Gabarra, 2009).
42 Currently, the last two mentioned predator species are reared by several private companies and
43 largely used in IPM and biological control programmes throughout Europe, while in North America
44 the most promising agent for pest control on the tomato crop is *D. hesperus* Knight (McGregor et
45 al., 1999; Sanchez et al., 2003; Shipp and Wang, 2006).
46 In the Mediterranean Basin and Europe, the tomato crop has recently been affected by the new
47 exotic pest *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), which is able to cause serious yield
48 losses with its larval feeding activity (Desneux et al., 2010). Native to South America, it was first
49 reported in Europe in 2006 and in Italy in 2008 (Urbaneja et al., 2009; Viggiani et al., 2009). The
50 tomato borer is a very challenging pest to control by chemicals due to its high reproduction rate and
51 potential to develop resistance to insecticides, as well as the side effects on beneficial organisms
52 used in IPM programmes (Siqueira et al., 2000; Lietti et al., 2005; Cabello et al., 2009a; Roditakis
53 et al., 2013). Research on indigenous predators and parasitoids able to control this exotic borer has
54 been carried out throughout the Mediterranean area. Several species of predators, such as *D.*

55 *tamaninii*, *M. pygmaeus*, *N. tenuis*, and *Nabis pseudoferus* (Remane) (Hemiptera: Nabidae)
 56 (Cabello et al., 2009b; Urbaneja et al., 2009; Desneux et al., 2010; Guenaoui et al., 2011; Urbaneja
 57 et al., 2012), as well as parasitoids such as *Necremnus* spp. (Hymenoptera: Eulophidae), *Agathis*
 58 *fuscipennis* (Zetterstedt) and *Bracon nigricans* Szepilgeti (Hymenoptera: Braconidae) (Cabello et
 59 al., 2009a; Loni et al., 2011; Biondi et al 2012 Ferracini et al., 2012a; Zappalà et al., 2012), have
 60 been evaluated for their effectiveness as natural enemies of the tomato borer.

61 Among predators, both commercialized dicyphine species, *M. pygmaeus* and *N. tenuis*, were proven
 62 to prey on eggs and larval stages of *T. absoluta*. In laboratory, the number of preyed eggs (from 10
 63 to 100 day⁻¹) varied in relation to the bug species, the sex, and also the number of daily offered eggs
 64 (10, 20, 40, 60, 145), while among the larval instars the 1st-instar was preferred with 1.8 and 2.4
 65 larvae daily consumed by *M. pygmaeus* and *N. tenuis*, respectively (Arnò et al., 2009; Mollà et al.,
 66 2009; Urbaneja et al., 2009). The predatory activities of these two species have also been reported
 67 in Italian protected tomato crops (Viggiani et al., 2009; Fois et al., 2011). In Piedmont, a more
 68 continental region in northwestern Italy, the indigenous dicyphine predators usually found in IPM
 69 tomato crops are *D. errans* and *M. pygmaeus* (Tavella and Goula, 2001; Ingegno et al., 2009)
 70 instead of *N. tenuis*, which has its northernmost distribution limit in Liguria, the coastal region of
 71 northwestern Italy (Arzone et al., 1990). While several studies have been carried out on both
 72 commercialized species, little is known about the effectiveness of the native *D. errans* as a predator
 73 of *T. absoluta*, which has largely been found in infested tomato plantations (Boualem et al., 2011;
 74 Ferracini et al., 2012b).

75 This mirid is a Palaearctic species widespread throughout Europe, except in Finland, Latvia,
 76 Lithuania, northern Ireland, northern Russia and Slovakia, and western Asia (Kerzhner and Josifov,
 77 1999; Aukema, 2005). In Italy its presence has been reported everywhere (Servadei, 1967; Faraci
 78 and Rizzotti Vlach, 2003). It lives omnivorously on various host plants (over 150), preying on a
 79 wide range of small arthropods (at least 15) (Voigt, 2005). Among plants, it prefers glandular hairy
 80 plants such as tomato, eggplant *Solanum melongena* L., potato *S. tuberosum* L., European black

81 nightshade *S. nigrum* L. (Solanaceae), courgette *Cucurbita pepo* L. (Cucurbitaceae), *Calendula*
82 *officinalis* L. (Asteraceae), *Geranium* spp., *Pelargonium* spp. (Geraniaceae), *Stachys sylvatica* L.
83 (Lamiaceae) and *Urtica dioica* L. (Urticaceae) (Arzone et al., 1990; Calabrò and Nucifora, 1993;
84 Tavella and Goula, 2001; Voigt, 2005; Ingegno et al., 2008) as a living substrate because of
85 morphological and behavioural adjustments (Voigt et al., 2007).
86 The present study aimed at investigating the predator capacity of *D. errans* and its potential role as
87 a biological control agent for the exotic tomato borer. In particular, predation rates on eggs and
88 larval instars of *T. absoluta*, survival and developmental time of the predator on this prey, and the
89 attractiveness of infested tomato were assessed under controlled conditions to evaluate if this
90 indigenous dicyphine species can be considered a promising candidate as a biological control agent
91 of the exotic tomato borer.

92

93 **2. Material and methods**

94 **2.1. Plant cultivation and insect rearing**

95 Tomato plants, cv Marmande, approximately 25 cm in height, were used for both mass-rearing and
96 laboratory trials. Seeds were sown in plastic pots (Ø 20 cm), watered daily and fertilized. All
97 tomato plants were cultivated in an open-sided greenhouse at 27 ± 3 °C, and $55 \pm 23\%$ RH, under a
98 photoperiod of 12 hours.

99 *D. errans* was collected on the European black nightshade *S. nigrum* in different localities of
100 Piedmont (NW Italy) and reared on tomato plants. The mirids were fed with eggs of *Ephestia*
101 *kuehniella* Zeller (Lepidoptera: Pyralidae) (Bioplanet Sca, Forlì Cesena, Italy) and reared inside a
102 cubic insect cage, 47.5 cm along each edge (MegaView, Taiwan), at 24 ± 1 °C, 55 ± 5 % RH, with a
103 16:8 L:D photoperiod to maintain the colonies. For the predation trials, newly emerged females and
104 males of *D. errans* were isolated in cages to allow them to mate; they were then used in the
105 experiments at different ages, i.e., five-, 10-, 15-days-old.

106 A continuous mass-rearing of all development stages of *T. absoluta* was maintained on tomato
107 plants in an open-sided greenhouse, in cages (150 by 150 by 110 cm) with a stainless steel frame
108 structure supporting an insect-proof net (mesh 0.23×0.23), starting from an initial culture collected
109 from commercial tomato plantations in Liguria (NW Italy).

110 **2.2. Predation trials on eggs**

111 Healthy tomato plants were periodically exposed to adults of *T. absoluta* to obtain a synchronized
112 cohort of eggs. Fifteen eggs were gently transferred under a stereomicroscope with the aid of a thin
113 brush onto a healthy stem with three leaflets. Each stem was put in a 2 ml plastic tube filled with
114 fertilized water and sealed with Parafilm[®]. Then, they were individually placed inside a Petri dish
115 (\varnothing 9 cm) on wet coarse paper to maintain leaf turgor during the experiments.

116 Five-, 10- and 15-day-old females and males of *D. errans* were placed individually inside the Petri
117 dish for 24 hours and the number of preyed eggs was then recorded. Before using them in the
118 experiments, the individuals were isolated for 24 hours in a glass tube with a healthy tomato leaf,
119 providing only water to ensure they were starved. Ten replicates were carried out for each sex and
120 age of the mirid, and their feeding activity was evaluated by counting consumed and healthy eggs.
121 Ten replicates without predator introduction were performed as a control. The experiment was
122 carried out in a climatic chamber at 25 ± 1 °C, $60 \pm 10\%$ RH, and 16:8 L:D.

123 **2.3. Predation trials on larvae**

124 A preliminary trial was performed to assess whether the predator showed any preference for
125 different larval instars. For this purpose, five larvae of each instar (1st, 2nd, 3rd, 4th) were exposed
126 simultaneously to five-day-old females and males of *D. errans* starved for 24 hours. The larvae
127 were gently transferred under a stereomicroscope with the aid of a thin brush onto a healthy tomato
128 stem with four leaflets, for a total of 20 larvae stem⁻¹. Each stem was put in a 2 ml plastic tube filled
129 with fertilized water and sealed with Parafilm[®]. Then, they were individually placed inside a Petri
130 dish (\varnothing 20 cm) on wet coarse paper to maintain leaf turgor during the experiments. The

consumption rate was evaluated after 24 hours of exposure, counting depleted and healthy larvae. Five replicates were carried out for both sexes of the mirid. To evaluate the effectiveness of *D. errans* as a biocontrol agent, five newly hatched larvae of the tomato borer (< 1-day old) were placed on a stem in a Petri dish as described above in the preliminary trial. After 24 hours of starvation inside a glass tube with a healthy tomato leaf and a water source, five- and 10-day-old females and males were individually placed inside the Petri dish for 24 hours and the number of preyed larvae was recorded. Ten replicates were performed for each sex and age of the mirid, and feeding activity was evaluated by counting consumed and healthy larvae. Ten stems in dishes without predator introduction were also set up as a control. All trials were carried out in a climatic chamber at 25 ± 1 °C, $60 \pm 10\%$ RH, and 16:8 L:D.

2.4. Developmental trials

Developmental time from egg hatching to adulthood and mortality rates of *D. errans* were investigated on tomato leaves in the presence of eggs or 1st-instar larvae of *T. absoluta* in comparison with *E. kuehniella* eggs as a control. For the experiments, 15 fresh eggs or five newly hatched larvae (<1-day old) of the tomato borer, or 15 *E. kuehniella* eggs, were gently transferred onto a tomato stem in a Petri dish as described above, and individually offered to a 1st-instar mirid nymph (<1-day old). Prey consumption, survival and moulting were recorded daily until the adult stage, while leaflets and food were replaced every two days. All emerged adults were examined under a stereomicroscope to determine their sex and measure their length (from vertex to the end of the hemielytra) in order to detect any difference in size between the diets. For each diet (i.e., *T. absoluta* eggs and larvae, and *E. kuehniella* eggs) 30 replicates were performed. The trials were carried out in a climatic chamber at 25 ± 1 °C, $60 \pm 10\%$ RH, and 16:8 L:D.

2.5. Olfactometer bioassays

One-week-old adults of *D. errans* were used to assess their olfactory preference between the odours of tomato plants either uninfested or infested by *T. absoluta*. In particular, six comparisons were performed using healthy leaves, eggs, 1st- and 4th-larval instars, adults, and leaves previously

infested by the tomato borer, obtained by removing all larvae with the aid of a thin brush and leaving only larval frass (Table 1). Before using them in olfactometer bioassays, adults were kept without neither prey nor plant in a glass tube (length 12 cm, Ø 2.3 cm) for 18 hours. The bioassays were carried out in a vertical Y-shaped Pyrex tube following the procedure described for another predatory bug, *M. pygmaeus* (Ingegno et al., 2011). Each individual was observed until it had walked at least 6 cm up one of the side arms or until 20 min had elapsed. Adults that did not choose a side arm within 20 min were considered as “no choice” and were not counted in the subsequent data analysis. For each test, an adult was evaluated only once to prevent any behaviour conditioning by experience. The odour sources chosen by the mirid that responded were recorded. Thirty responses were recorded for each pair of odour sources. After testing five adults, the odour sources were switched between the left-hand and right-hand side arms to minimize any spatial effect on choices. The Y-tube and cameras were cleaned with mild soap and alcohol (70%v) and sterilized in an autoclave at 120°C for 20 min. The olfactory bioassays were conducted at 24 ± 2 °C, $50 \pm 10\%$ RH, and 150 ± 10 lux.

2.6. Statistical analyses

After testing for homogeneity of variance (Levene) and normality (Shapiro-Wilk), data on egg and 1st-instar larva predation were analysed by one-way analysis of variance (ANOVA) and means were compared by Tukey’s test. Since they were not normally distributed, data on preference for larval instars, developmental time, and adult body length were analysed by Kruskal Wallis and means were separated by the Mann-Whitney U test. In the olfactometer bioassays, the responses of *D. errans* females were analysed by a chi-square test. The null hypothesis was that predatory females had a 50:50 distribution across the two odour sources. Females that did not make a choice were excluded from the statistical analysis. All analyses were performed using the software SPSS version 17.0 (SPSS, Chicago, IL).

181

3. Results

Both females and males of *D. errans* proved to prey on *T. absoluta* eggs. Predation rates were relatively high, ranging from 6.4 ± 1.5 to 12.4 ± 0.7 eggs day⁻¹, corresponding to 42.7% and 82.7% of total offered eggs, for 15-day-old males and 10-day-old females, respectively (Table 2). Overall, females showed a significantly higher consumption rate: in fact, 11.0 ± 0.7 and 8.6 ± 0.8 eggs day⁻¹, corresponding to $73.6 \pm 4.3\%$ and $57.6 \pm 5.4\%$ of offered eggs, were consumed on average by females and males, respectively (ANOVA: df = 1, 58, F = 5.30, P = 0.025). A significantly smaller number of eggs was preyed upon by 15-day-old males compared to 10- or 15-day-old females (ANOVA: df = 5, 54, F = 3.32, P = 0.011). In the control without predator after 24 hours, the eggs were still turgid and then hatched.

When different instar larvae were provided simultaneously to *D. errans*, both sexes accepted only 1st-instar larvae as preys, except for a small percentage (4%) of predation on 2nd-instar larvae by females. By contrast, 3rd- and 4th- larvae showed no evidence of predation (Kruskal Wallis: df = 3; $\chi^2 = 35.24$, P < 0.001) (Table 3). When five 1st-instar larvae were offered for 24 hours, females were more effective than males, preying on an average of 2.40 ± 0.54 and 1.30 ± 0.29 larvae, respectively (ANOVA: df = 1, 38, F = 7.79, P = 0.008) (Fig. 1). Also on 1st-instar larvae, older males (10-days-old) were the least effective predators (Kruskal Wallis: df = 3, $\chi^2 = 8.33$, P = 0.040) compared to females (Fig. 1). In the control without predator after 24 hours, the larvae were still alive.

In the developmental trials, *D. errans* nymphs could develop on all diets; but they showed evident difficulties preying on 1st-instar larvae of *T. absoluta*, attested by their high mortality (89.3%) (Table 4). However, the high mortality rates of 2nd-, 3rd- and 4th-instar nymphs preying on 1st-instar larvae of the tomato borer were also associated with significantly shorter instar duration. Developmental time from egg hatching to adulthood was significantly shorter on tomato leaves with *E. kuehniella* eggs (20.38 ± 0.75 days) than with *T. absoluta* eggs (24.12 ± 1.05) (Kruskal Wallis: df = 2, $\chi^2 = 5.98$, P = 0.05) (Table 4). By contrast, no statistically significant differences were found in body length between diets within sexes, even if the mean size was smaller with *T. absoluta* eggs

209 as diet (males, ANOVA: $df = 2, 23$, $F = 0.59$, $P = 0.56$; females, ANOVA: $df = 2, 31$, $F = 0.89$, $P =$
210 0.42) (Table 4).

211 In olfactory bioassays, *D. errans* proved to be more attracted by tomato infested by the tomato borer
212 compared to uninfested tomato. In particular, significant differences in the responses of adults were
213 found when healthy tomato was compared with a previously infested one ($\chi^2 = 4.83$, $P = 0.03$), and
214 with tomato infested by 1st- or 4th-instar larvae of *T. absoluta* ($\chi^2 = 4.83$, $P = 0.03$; $\chi^2 = 6.53$, $P =$
215 0.01) (Fig. 2). On the contrary, no statistically significant differences were found between
216 uninfested tomato *versus* *T. absoluta* adults ($\chi^2 = 1.20$, $P = 0.27$), or *versus* tomato with *T. absoluta*
217 eggs ($\chi^2 = 3.33$, $P = 0.07$), and between plants infested by 1st-instar larvae and 4th-instar larvae ($\chi^2 =$
218 3.33 , $P = 0.07$) (Fig. 2).

219

220 4. Discussion and conclusions

221 To control a cosmopolitan pest, as *T. absoluta* has become, exploration of the efficiencies of several
222 biological control agents suitable to different habitats is almost compulsory. Generalist predator
223 species belonging to Miridae Dicyphini live in different habitats and have a wide host plant range
224 that makes them suitable candidates for use as biological control agents in different environments.
225 In particular, *D. errans* has a distribution area similar to *M. pygmaeus*, whereas it is more
226 continental than *N. tenuis*, being reported mainly in localities with a mild climate along the
227 Mediterranean coast (Kerzhner and Josifov, 1999; Aukema, 2005). Regarding the host range, some
228 plants are known as natural hosts for all three species [tomato, pepper *Capsicum annuum* L.,
229 *Dittrichia viscosa* (L.) Greuter, *C. officinalis*, *S. nigrum*] (Tavella and Goula, 2001; Cano et al.,
230 2009) even if *D. errans* seems to have a wider host plant range, as so far it has been reported on
231 more than 150 plant species (Voigt, 2005).

232 In Italy, all three dicyphine species, *D. errans*, *M. pygmaeus* and *N. tenuis*, are naturally present and
233 able to establish on IPM tomato crop if not disturbed by chemical treatments; however, they have
234 been found to colonize the crop in different areas in relation to environmental conditions and wild

235 flora (Tavella and Goula, 2001; Ingegno et al., 2009). In Piedmont, the predominance of *D. errans*
 236 may be due to the natural abundance of *S. nigrum*, one of the most favourite hosts of this species as
 237 well as of *M. pygmaeus* (Tavella et al., 1997; Lykouressis et al., 2000; Perdakis et al., 2008,
 238 Ferracini et al., 2012b). In our climate, this cosmopolitan annual herbaceous plant blooms from
 239 March to November and is very common in pioneer nitrophilic communities that often surround
 240 tomato crop (Pignatti, 1982; Ingegno et al., 2009). *D. errans* is able to colonize tomato early in the
 241 season when it is present in the surroundings (Ingegno et al., 2009). Moreover, since it shares some
 242 other host plants with *T. absoluta* (i.e., *S. melongena*, *S. nigrum*, *S. tuberosum*, *Datura* spp.,
 243 *Nicotiana* spp.) (EPPO, 2005; Voigt, 2005), this predator could carry on a strategic control role
 244 throughout the whole pest cycle.

245 In this study, the ability of the indigenous *D. errans* to prey on *T. absoluta* is reported for the first
 246 time. Previous studies showed that both commercialised dicyphine species, *M. pygmaeus* and *N.*
 247 *tenuis*, prey actively on *T. absoluta* (Arnó et al., 2009; Urbaneja et al., 2009, 2012; Mollá et al.,
 248 2009). In our experiments, *D. errans* showed to accept the tomato borer as prey. On *T. absoluta*
 249 eggs, adult predators were able to consume more than 10 eggs daily on 15 eggs total offered. This
 250 rate was certainly lower in comparison with numbers of eggs consumed by *M. pygmaeus* and *N.*
 251 *tenuis*, when higher amounts of eggs were provided (Arnó et al., 2009; Urbaneja et al., 2009; Mollá
 252 et al., 2009). However, since the consumption rate could vary in relation to the amount of offered
 253 eggs, the actual effectiveness of *D. errans* should be further assessed by offering bug adults
 254 different amounts of eggs. Overall, females of *D. errans* consumed eggs at a significantly higher
 255 rate compared to males ($73.6 \pm 4.3\%$ against $57.6 \pm 5.4\%$) as it has also been observed for two other
 256 species (Urbaneja et al., 2009). Older females (10- and 15-days-old) were hungrier than older males
 257 (15-days-old), probably due to the effort of mature egg production. In fact, the pre-oviposition
 258 period of closely related species lasts between 3 and 6 days (Agustí and Gabarra, 2009), and it is
 259 known that predatory abilities can also change with age (Abrams, 2000).

260 In a simultaneous exposure to different larval instars of *T. absoluta*, both sexes of *D. errans*
261 preferred 1st-instar larvae, which are less mobile and smaller in size; only one female accepted 2nd-
262 instar larvae and none chose the latter two instars. On the contrary, *M. pygmaeus* and *N. tenuis* were
263 able to accept all larval instars even if they showed a preference for the 1st-instar (Urbaneja et al.,
264 2009). Overall, males and females of the indigenous predator preyed on a significantly different
265 number of 1st-instar larvae (2.4 ± 0.5 and 1.3 ± 0.3 larvae day⁻¹, respectively, on average), while no
266 differences between the sexes were reported for *M. pygmaeus* and *N. tenuis*, which preyed on about
267 2 larvae day⁻¹ (Urbaneja et al., 2009).

268 Furthermore, in order to assess the potential of a species as a biological control agent it is important
269 to take into account the time from egg to adulthood of both the predator and its prey. When the
270 developmental time of a generalist predator is long compared to its prey, the predators are unlikely
271 to be effective classical biological control agents because their abundance is strongly regulated by
272 cannibalism (Kindlmann and Dixon, 1999, 2001, 2002; Hamdi et al., 2013). The duration of the life
273 cycle of *T. absoluta* depends greatly on environmental conditions, varying from 23.8 days at 27.1°C
274 and 28.0 days at 25°C to 39.8 days at 19.7°C and 76.3 days at 14°C (Barrientos et al., 1998; Pereyra
275 and Sanchez, 2006). In the Mediterranean climate, adult *T. absoluta* can be detected all through the
276 year because there is no clear distinction between the generations (about 12 year⁻¹) that overlap
277 throughout the entire crop cycle (Vercher et al., 2010). In our experimental conditions, *D. errans*
278 proved to develop successfully on tomato infested with *T. absoluta* eggs: at 25°C more than 80% of
279 nymphs reached adulthood in 24.1 ± 1.1 days, a longer time than on tomato infested with *E.*
280 *kuehniella* eggs (20.4 ± 0.8 days) but still shorter compared to the life span of the pest under the
281 same conditions. This difference could be attributed to the smaller size of *T. absoluta* eggs, 360 µm
282 long and 220 µm in diameter (EPPO, 2005), in comparison to *E. kuehniella* eggs, 500–550 µm long
283 and 290–325 µm wide (Moreno et al., 1994), with a consequently reduced protein intake.

284 Differences in developmental time have also been observed in other dicyphine species reared on
285 different diets, such as artificial food, bee pollen, various preys and plants (Gillespie and McGregor,

286 2000; Perdikis and Lykouressis, 2000, Castañé et al., 2002). In previous studies on *M. pygmaeus*,
 287 90% of nymphs reached adulthood preying on *E. kuehniella* eggs at 24–25°C in 17–18 days
 288 (Grenier et al., 1989; Castañé and Zapata, 2005; Vanderkekhove et al., 2006). Development on *E.*
 289 *kuehniella* eggs was generally more rapid than on natural preys such as *Myzus persicae* Sulzer,
 290 *Trialeurodes vaporariorum* Westwood, and *Tetranychus urticae* Koch; on these preys
 291 developmental times were 27.0 days at 22°C, 29.4 days at 22°C and 35.7 days at 25°C, respectively
 292 (Fauvel et al., 1987; Tedeschi et al., 1999). The high mortality of 2nd-, 3rd-, and 4th-instar nymphs of
 293 *D. errans* feeding on 1st-instar larva of *T. absoluta* might be explained by the small size of the
 294 nymphs compared with the 5th-instar nymph and adult. By contrast, the complete survival of 1st-
 295 instar nymphs could be due to its only taking in nourishment from the plant; in fact, it is known that
 296 a basal level of plant feeding is necessary to provide water to sustain vital functions in dicyphine
 297 species (De Puyssleuyr et al., 2013). However, *T. absoluta* larvae would seem to be more nutritive
 298 for the predator, as the development time was shorter.
 299 Recently, both commercialised dicyphine species, *M. pygmaeus* and *N. tenuis*, have been used
 300 successfully in IPM and biological control programmes against the tomato borer (Belda et al., 2011;
 301 Harpaz et al., 2011; Jacobson, 2011; Mollá et al., 2011; Seguret et al., 2011, Urbaneja et al., 2012),
 302 advancing the opportunity to also use *D. errans* in more continental areas. These predators, if
 303 present in the surroundings, are usually attracted by volatile organic compounds emitted by healthy
 304 tomato plants as assessed in laboratory experiments for *M. pygmaeus* (Ingegno et al., 2011). In
 305 olfactometric assays used here for the first time on this dicyphine species, *D. errans* was more
 306 attracted by tomato plants infested with *T. absoluta*, when larvae of different instars were present
 307 and even when the larvae were removed. Probably residues of larval activity, together with
 308 chemical signals transmitted by injured plants, play an active role in tritrophic interactions. A
 309 greater attraction due to volatile organic compounds emitted by tomato plants after whitefly
 310 infestation was also observed in *M. pygmaeus* (Ingegno et al., 2011).

311 These results, besides underlining the great value of native fauna and the importance of preserving
312 its natural presence on crops, serve as the basis for further investigations on the efficacy of *D.*
313 *errans* as a pest predator. Therefore, further research is needed to evaluate its candidacy for mass
314 production as a biological control agent against the tomato borer. However, the predator, because of
315 its high performance on eggs and 1st-instar larvae, should be released on banker plants at the
316 beginning of the crop season to enhance early establishment.

317

318 **Acknowledgments**

319 We wish to thank Dr Marco Mosti of Bioplanet s.c.a. (Italy) for providing insects and Evaggelia
320 Kalaitzoglou for technical assistance.

321

322 **References**

- 323 Abrams, P.A., 2000. The evolution of predator-prey interactions: theory and evidence. *Annu. Rev.*
324 *Ecol. Syst.* 31, 79–105.
- 325 Agustí, N., Gabarra, R., 2009. Effect of adult age and insect density of *Dicyphus tamaninii* Wagner
326 (Heteroptera: Miridae) on progeny. *J. Pest. Sci.* 82, 241–246.
- 327 Alomar, Ò., Albajes, R., 1996. Greenhouse whitefly (Homoptera: Aleyrodidae) predation and
328 tomato fruit injury by the zoophytophagous predator *D. tamaninii* (Heteroptera: Miridae), in:
329 Alomar, Ò., Wiedenmann, R.N., (Eds.), *Zoophytophagous Heteroptera: implications for life history*
330 and integrated pest management, Thomas Say Publications in Entomology, Lanham, MD, Proc.
331 Entomol. Soc. Am., Lanham, Maryland, 155–177.
- 332 Alomar, Ò., Goula, M., Albajes, R., 2002. Colonisation of tomato fields by predatory mirid bugs
333 (Hemiptera: Heteroptera) in northern Spain. *Agric., Ecosyst. Environ.* 89, 105–115.
- 334 Arnó, J., Alonso, E., Gabarra, R., 2003. Role of the parasitoid *Diglyphus isaea* (Walker) and the
335 predator *Macrolophus caliginosus* Wagner in the control of leafminers. *IOBC WPRS Bull.* 26, 79–
336 84.
- 337 Arnó, J., Sorribas, R., Prat, M., Matas, M., Pozo, C., Rodriguez, D., Garreta, A., Gómez, A.,
338 Gabarra, R., 2009. *Tuta absoluta* a new pest in IPM tomatoes in the northeast of Spain. *IOBC*
339 *WPRS Bull.* 49, 203–208.
- 340 Arzone, A., Alma, A., Tavella, L., 1990. Ruolo dei Miridi (Rhynchota Heteroptera) nella
341 limitazione di *Trialeurodes vaporariorum* Westw. (Rhynchota Aleyrodidae). *Boll. Zool. Agrar.*
342 *Bachic.* 22 (1), 43–51.
- 343 Aukema B., 2005. Fauna Europaea: Hemiptera Heteroptera. In: Aukema B. (ed.), *Fauna Europaea:*
344 *Hemiptera Heteroptera, Bugs. Fauna Europaea version 2.4,*
345 http://www.faunaeur.org/full_results.php?id=452427/403/395.

346 Barrientos, Z.R., Apablaza, H.J., Norero, S.A., Estay, P.P., 1998. Temperatura base y constante
 347 térmica de desarrollo de la polilla del tomate, *Tuta absoluta* (Lepidoptera: Gelechiidae). Cienc.
 348 Investig. Agrar. 25, 133–137.

349 Belda, J.E., Giménez, A., Javier Calvo, F., 2011. Success and extension of biological control
 350 strategies for managing *Tuta absoluta* (Meyrick) (Lep. Gelechiidae) populations in the
 351 Mediterranean area. EPPO/IOBC/FAO/NEPPO Abstracts'book of the International Symposium on
 352 management of *Tuta absoluta* (tomato borer). Agadir, Morocco, November 16-18, 2011, 28.

353 Biondi, A., Siscaro, G., Desneux, N., Amiens-Desneux, E., Zappalà, L., 2012. Biology and
 354 behaviour of the indigenous parasitoid *Bracon nigricans* on the invasive South American tomato
 355 pinworm *Tuta absoluta*. IOBC/WPRS Bull. 80, 131.

356 Boualem, M., Hamadi, R., Allaoui, H.A., 2011. Study of parasitic complex of *Tuta absoluta* in
 357 Mostaganem area (Algeria). EPPO/IOBC/NEPPO Joint International Symposium on Management
 358 of *Tuta absoluta* (Tomato Borer), Agadir, Morocco, November 16-18, 2011, 58.

359 Cabello, T., Gallego, J.R., Vila, E., Soler, A., del Pino, M., Carnero, A., Hernández-Suárez, E.,
 360 Polaszek, A., 2009a. Biological control of the South American tomato pinworm, *Tuta absoluta*
 361 (Lep.: Gelechiidae), with releases of *Trichogramma achaeae* (Hym.: Trichogrammatidae) on
 362 tomato greenhouses of Spain. IOBC/WPRS Bull. 49, 225–230.

363 Cabello, T., Gallego, J.R., Fernandez-Maldonado, F.J., Soler, A., Beltran, D., Parra, A., Vila, E.,
 364 2009b. The damsel bug *Nabis pseudoferus* as a new biological control agent of the South American
 365 Tomato Pinkworm, *Tuta absoluta*, in tomato crops of Spain. IOBC/WPRS Bull. 49, 219–223.

366 Calabrò, M., Nucifora, A., 1993. Presenza di Miridi zoofitofagi (Rhynchota, Heteroptera) su
 367 pomodoro e altre piante e loro utilizzabilità come ausiliari. Boll. Accad. Gioenia Sci. Nat. 26 (342),
 368 115–131.

369 Cano, M., Vila, E., Janssen, D., Bretones, G., Salvador, E., Lara, L., Tellez, M.M., 2009. Selection
 370 of refuges for *Nesidiocoris tenuis* (Het.: Miridae) and *Orius laevigatus* (Het.: Anthocoridae): virus
 371 reservoir risk assessment. IOBC/WPRS Bull. 49, 281–286.

372 Carvalho, P., Mexia, A., 2000. First approach on the potential role of *Dicyphus cerastii* Wagner
 373 (Hemiptera: Miridae), as natural control agent in Portuguese greenhouses. IOBC/WPRS Bull. 23
 374 (1), 261–264.

375 Cassis, G., 1984. A systematic study of the subfamily Dicyphinae (Heteroptera: Miridae). Oregon
 376 State University Thesis.

377 Castañé, C., Iriarte, J., Lucas, E., 2002. Comparison of prey consumption by *Dicyphus tamaninii*
 378 reared conventionally, and on a meatbased diet. BioControl 47, 657–666.

379 Castañé, C., Alomar, Ò., Goula, M., Gabarra, R., 2004. Colonization of tomato greenhouses by the
 380 predatory mirid bugs *Macrolophus caliginosus* and *Dicyphus tamaninii*. Biol. Control 30, 591–597.

381 Castañé, C., Zapata R., 2005. Rearing the predatory bug *Macrolophus caliginosus* on a meat-based
 382 diet. Biol. Control 34 (1), 66–72.

383 De Puyseleir, V., De Man, S., Höfte, M., De Clercq, P., 2013. Plantless rearing of the
 384 zoophytophagous bug *Nesidiocoris tenuis*. Biocontrol 58, 205–213.

385 Desneux, N., Wajinberg, E., Wyckhuys, K.A.G., Burgio, G., Arpaia, S., Nárvaez-Vasquez, C.A.,
 386 González-Cabrera, J., Catálan Ruescas, D., Tabone, E., Frandon, J., Pizzol, J., Poncet, C., Cabello,
 387 T., Urbaneja, A., 2010. Biological invasion of European tomato crops by *Tuta absoluta*: ecology,
 388 geographic expansion and prospects for biological control. J. Pest. Sci. 83, 197–215.

389 EPPO, 2005. Data sheets on quarantine pests *Tuta absoluta*. EPPO Bull. 35, 434–435.

390 Faraci, F., Rizzotti Vlach, M., 2003. Heteroptera. In: Checklist of the species of the Italian fauna.
 391 Stoch, F. (ed.). On-line version 2.0. <http://checklist.faunaitalia.it>.

392 Fauvel, G., Malausa, J.C., Kaspar, B., 1987. Etude en laboratoire des principales caracteristiques
 393 biologiques de *Macrolophus caliginosus* (Heteroptera: Miridae). Entomophaga 32, 529–543.

394 Ferracini, C., Ingegno, B.L., Navone, P., Ferrari, E., Mosti, M., Tavella, L., Alma, A., 2012a.
 395 Adaptation of Indigenous Larval Parasitoids to *Tuta absoluta* (Lepidoptera: Gelechiidae) in Italy. J.
 396 Econ. Entomol. 105 (4), 1311–1319.
 397 Ferracini, C., Ingegno, B.L., Mosti, M., Navone, P., Tavella, L., Alma, A., 2012b. Promising native
 398 candidates for biological control of *Tuta absoluta* (Meyrick) in Italy. IOBC/WPRS Bull. 80, 51–55.
 399 Fois, F., Porcu, M., Sau, S., Carrusci, P., Deiana, M., Nannini, M., 2011. Valutazioni preliminari
 400 del predatore *Macrolophus pygmaeus* (Hemiptera, Miridae) nel contenimento di *Tuta absoluta*
 401 (Lepidoptera, Gelechiidae). Atti XXIII Congr. Naz. Entomol. Genova, 337.
 402 Gillespie, D.R., McGregor, R.R., 2000. The functions of plant feeding in the omnivorous predator
 403 *Dicyphus hesperus*: water places limits on predation. Ecol. Entomol. 25, 380–386.
 404 Grenier, S., Guillaud, J., Delobel, B., Bonnot, G., 1989. Nutrition et élevage du prédateur polyphage
 405 *Macrolophus caliginosus* (Heteroptera: Miridae) sur milieux artificiels. Entomophaga 34, 77–86
 406 Guenaoui, Y., Bensaad, R., Ouezzani, K., 2011. Importance of native polyphagous predators able to
 407 prey on *Tuta absoluta* Meyrich (Lepidoptera: Gelechiidae) on tomato crop.
 408 EPPO/IOBC/FAO/NEPPO Abstracts'book of the International Symposium on management of *Tuta*
 409 *absoluta* (tomato borer). Agadir, Morocco, November 16-18, 2011, 30.
 410 Hamdi, F., Chadoeuf, J., Chermiti, B., Bonato, O., 2013. Evidence of cannibalism in *Macrolophus*
 411 *pygmaeus*, a natural enemy of whiteflies. J. Insect Behav., DOI 10.1007/s10905-013-9379-3.
 412 Harpaz, L.S., Graph, S., Rika, K., Azolay, L., Rozenberg, T., Yakov, N., Alon, T., Alush, A.,
 413 Stinberg, S., Gerling, D., 2011. IPM of *Tuta absoluta* in Israel. EPPO/IOBC/FAO/NEPPO
 414 Abstracts'book of the International Symposium on management of *Tuta absoluta* (tomato borer).
 415 Agadir, Morocco, November 16-18, 2011, 32.
 416 Ingegno, B.L., Goula, M., Navone, P., Tavella, L., 2008. Distribution and host plants of the genus
 417 *Dicyphus* in the Alpine valleys of NW Italy. Bull. Insectol. 61 (1), 139–140.
 418 Ingegno, B.L., Pansa, M.G., Tavella, L., 2009. Tomato colonization by predatory bugs
 419 (Heteroptera: Miridae) in agro-ecosystems of NW Italy. IOBC/WPRS Bull. 49, 287–291.

420 Ingegno, B.L., Pansa, M.G., Tavella, L., 2011. Plant preference in the zoophytophagous generalist
 421 predator *Macrolophus pygmaeus* (Heteroptera: Miridae). Biol. Control 58 (3), 174–181.

422 Jacobson, R., 2011. *Tuta absoluta*: A season- long IPM strategy based on predatory bugs.
 423 EPPO/IOBC/FAO/NEPPO Abstracts'book of the International Symposium on management of *Tuta*
 424 *absoluta* (tomato borer). Agadir, Morocco, November 16-18, 2011, 33.

425 Kerzhner, I.M., Josifov, M., 1999. Cimicomorpha II: Miridae. Vol 3 in Aukema B., Rieger C.:
 426 Catalogue of the Heteroptera of the Palaearctic Region. Wageningen, The Netherlands, 577.

427 Kindlmann, P., Dixon, A.F.G., 1999. Generation time ratios-determinants of prey abundance in
 428 insect- predator-prey interactions. Biol. Control 16, 1333–1138.

429 Kindlmann, P., Dixon, A.F.G., 2001. When and why top-down regulation fails in arthropod
 430 predator-prey systems. Basic Appl. Ecol. 2, 333–340.

431 Kindlmann, P., Dixon, A.F.G., 2002. Insect predator-prey dynamics and the biological
 432 control of aphids by ladybirds. Proc. 1st Int. Symp. Biol. Control Arthropods, Honolulu, Hawaii,
 433 USA, January 14-18, 2002, 118–124.

434 Lietti, M.M.M., Botto, E., Alzogaray, R.A., 2005. Insecticide resistance in Argentine populations of
 435 *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Neotrop. Entomol. 34, 113–119.

436 Loni, A., Rossi, E., van Achterberg, K., 2011. First report of *Agathis fuscipennis* in Europe as
 437 parasitoid of the tomato leafminer *Tuta absoluta*. Bull. Insectol. 64 (1), 115–117.

438 Lykouressis, D., Perdikis, D., Tsagarakis, A., 2000. Polyphagous mirids in Greece: host plants and
 439 abundance in traps placed in some crops. Boll. Lab. Entomol. Agrar. Filippo Silvestri 56, 57–68.

440 Lykouressis, D., Giatropoulos, A., Perdikis, D.C., Favas, C., 2008. Assessing the suitability of non-
 441 cultivated plants and associated insect prey as food sources for the omnivorous predator
 442 *Macrolophus pygmaeus* (Hemiptera: Miridae). Biol. Control 44, 142–148.

443 Malausa, J.C., 1989. Lutte intégrée sous serre: les punaises prédatrices Mirides dans les cultures de
 444 Solanacées du sud-est de la France. Rev. Hortic. 298, 39–43.

445 Malausa, J.C., Trottin-Caudal, Y., 1996. Advances in the strategy of use of the predaceous bug
 446 *Macrolophus caliginosus* (Heteroptera: Miridae) in glasshouse crops in: Alomar, Ò., Wiedenmann,
 447 R.N., (Eds.), Zoophytophagous Heteroptera: implications for life history and integrated pest
 448 management, Thomas Say Publications in Entomology, Lanham, MD, Proc. Entomol. Soc. Am.,
 449 Lanham, Maryland, 178–189.

450 McGregor, R.R., Gillespie D.R., Park C.G., Quiring D.M.J., Foisy, M.R.J., 1999. Potential use of
 451 *Dicyphus hesperus* Knight (Heteroptera: Miridae) for biological control of pests of greenhouse
 452 tomatoes. Biol. Control 16, 104–110.

453 Mollá, Ó., Montón, H., Vanaclocha, P.; Beitia, F.; Urbaneja, A., 2009. Predation by the mirids
 454 *Nesidiocoris tenuis* and *Macrolophus pygmaeus* on the tomato borer *Tuta absoluta*. IOBC/WPRS
 455 Bull. 49, 209–214.

456 Mollá, Ó., González-Cabrera, J., Urbaneja, A., 2011. The combined use of *Bacillus thuringiensis*
 457 and *Nesidiocors tenuis* against the tomato borer *Tuta absoluta*. Biocontrol 56: 883-891.

458 Moreno, J., Barry, P., Jimenez, R., 1994. Morphological changes on the egg surface of *Ephestia*
 459 *kuehniella* Zeller (Lepidoptera: Pyralidae) after parasitization by *Phanerotoma* (*Phanerotoma*)
 460 *ocularis* Kohl (Hymenoptera: Braconidae). Appl. Entomol. Zool. 29 (2), 282–284.

461 Perdikis D.C., Lykouressis D.P., 2000. Effects of various items, host plants, and temperatures on
 462 the development and survival of *Macrolophus pygmaeus* Rambur (Hemiptera: Miridae). Biol.
 463 Control 17, 55–60.

464 Perdikis, D.C., Kapaxidi, E., Papadoulis, G., 2008. Biological control of insect and mite pests in
 465 greenhouse solanaceous crops. Eur. J. Plant Sci. Biotechnol. 2 (1), 125–144.

466 Pereyra, P.C. and Sánchez, N.E., 2006: Effect of two solanaceous plants on developmental and
 467 population parameters of the tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera:
 468 Gelechiidae). Neotrop. Entomol. 35, 671–676.

469 Pignatti, S., 1982. Flora d'Italia. Vol. secondo, Bologna, Edagricole, 514.

470 Roditakis, E. , Skarmoutsou, C., Staurakaki, M., 2013. Toxicity of insecticides to populations of
 471 tomato borer *Tuta absoluta* (Meyrick) from Greece. *Pest Manag. Sci.* 69, 834–840.

472 Sanchez, J.A., Gillespie, D.R., McGregor, R.R., 2003. The effects of mullein plants (*Verbascum*
 473 *thapsus*) on the population dynamics of *Dicyphus hesperus* (Heteroptera: Miridae) in tomato
 474 greenhouses. *Biol. Control* 28, 313–319.

475 Sanchez, J.A., Gillespie, D.R., McGregor, R.R., 2004. Plant preference in relation to life history
 476 traits in the zoophytophagous predator *Dicyphus hesperus*. *Entomol. Exp. Appl.* 112, 7–19.

477 Seguret, J., Maignet, P., Ridray, G., 2011. Efficacy of the combination of two beneficials to control
 478 *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae) in tomato glasshouses in southern
 479 France. EPPO/IOBC/FAO/NEPPO Abstracts'book of the International Symposium on management
 480 of *Tuta absoluta* (tomato borer). Agadir, Morocco, November 16-18, 2011, 47.

481 Servadei, A., 1967. Rhynchota (Heteroptera, Homoptera Auchenorrhyncha). Catalogo topografico e
 482 sinonimico, in: Fauna d'Italia, 9. Calderini, Bologna, 1–851.

483 Shipp, J.L., Whang, K., 2006. Evaluation of *Dicyphus hesperus* (Heteroptera: Miridae) for
 484 biological control of *Frankliniella occidentalis* (Thysanoptera: Thripidae) on greenhouse tomato. *J.*
 485 *Econ. Entomol.* 99 (2), 414–420.

486 Siqueira, H.A.A., Guedes, R.N.C., Picanco, M.C., 2000. Insecticide resistance in populations of
 487 *Tuta absoluta* (Lepidoptera: Gelechiidae). *Agric. For. Entomol.* 2, 147–153.

488 Tavella, L., Alma, A., Sargiotto, C., 1997. Samplings of Miridae Dicyphinae in tomato crops of
 489 Northwestern Italy. *IOBC/WPRS Bull.* 20, 249–256.

490 Tavella, L., Goula, M., 2001. Dicyphini collected in horticultural areas of north-western Italy
 491 (Heteroptera Miridae). *Boll. Zool. Agrar. Bachic.* 33 (1), 93–102.

492 Tedeschi, R., Clercq, P., de Veire, M. van de Tirry, L., 1999. Development and predation of
 493 *Macrolophus caliginosus* (Heteroptera: Miridae) on different prey. *Proc. 51st Int. symp. on crop*
 494 *prot., Gent, Belgium, 4 May 1999. Part I, 64 (3a): 235–240.*

495 Urbaneja, A., Montón, H., Mollá, O., 2009. Suitability of the tomato borer *Tuta absoluta* as prey for
 496 *Macrolophus pygmaeus* and *Nesidiocoris tenuis*. J. Appl. Entomol. 133, 292–296.
 497 Urbaneja, A., González-Cabrera, J., Arnó, J., Gabarra, R., 2012. Prospects for the biological control
 498 of *Tuta absoluta* in tomatoes of the Mediterranean Basin. Pest. Manag. Sci. 68, 1215–1222.
 499 Vandekerkhove, B., Van Baal, E., Bolckmans, K., De Clercq, P., 2006. Effect of diet and mating
 500 status on ovarian development and oviposition in the polyphagous predator *Macrolophus*
 501 *caliginosus* (Heteroptera: Miridae). Biol. Control 39, 532–538.
 502 Vercher, R., Calabuig, A., Felipe, C., 2010. Ecología, muestreos y umbrales de *Tuta absoluta*
 503 (Meyrick). Phytoma Esp. 217, 23–26.
 504 Viggiani, G., Filella, F., Delrio, G., Ramassini, W., Foxi, C., 2009. *Tuta absoluta*, nuovo lepidottero
 505 segnalato anche in Italia. Inf. Agr. 2, 66–68.
 506 Voigt, D., 2005. Untersuchungen zur Morphologie, Biologie und Ökologie der räuberischen
 507 Weichwanze *Dicyphus errans* Wolff (Heteroptera, Miridae, Bryocorinae). Dissertation, TU
 508 Dresden, Germany.
 509 Voigt, D., Gorb, E., Gorb, S., 2007. Plant surface–bug interactions: *Dicyphus errans* stalking along
 510 trichomes. Arthropod-Plant Interact. 1 (4), 221–243.
 511 Zappalà, L., Bernardo, U., Biondi, A., Cocco, A., Deliperi, S., Delrio, G., Giorgini, M., Pedata, P.,
 512 Rapisarda, C., Tropea Garzia, G., Siscaro, G., 2012. Recruitment of native parasitoids by the exotic
 513 pest *Tuta absoluta* in Southern Italy. Bull. Insectol. 65 (1), 51–61.
 514

515 **Figure 1.** Average number (\pm SE) of 1st-instar *T. absoluta* larvae preyed on by *D. errans*. Ten
516 replicates were performed for each sex and age (5 and 10 days). Bars topped by the same lower-
517 case letter represent means that are not statistically different (ANOVA, $P < 0.05$). Bold-case letters
518 are referred to the comparison between total females and males (ANOVA, $P < 0.05$).

519
520 **Figure 2.** Responses of *D. errans* in a Y-tube olfactometer to the odours of healthy tomato (α),
521 adults of *T. absoluta* (β), tomato infested with eggs (π), 1st-instar larvae (γ) and 4th-instar larvae (δ)
522 of *T. absoluta*, or tomato previously infested with *T. absoluta* (ϵ), for each compared pair. Numbers
523 in bars represent individuals that moved toward the volatiles. χ^2 statistics (* $P < 0.05$; DF:1) tested
524 the hypothesis that the distribution of side-arm choices deviated from a null model where odour
525 sources were chosen with equal frequency.

1 **Table 1.** Comparison of treatments in olfactometric bioassays.

odour source 1		odour source 2
		<i>T. absoluta</i> adults
		tomato infested with eggs
healthy tomato	vs	tomato infested with 1 st -instar larvae
		tomato infested with 4 th -instar larvae
		tomato previously infested with larvae
tomato infested with 1 st -instar larvae	vs	tomato infested with 4 th -instar larvae

2

Table 2

Table 2. Number (mean \pm SE) of *T. absoluta* eggs preyed on by 5-, 10- and 15-day-old females and males of *D. errans* from 15 eggs offered for 24 hours. Means followed by different letters are significantly different (Tukey’s test, $P < 0.05$).

Adult age (d)	% of eggs preyed on by	
	females	males
5	9.1 \pm 1.4 ab	10.8 \pm 1.3 ab
10	12.4 \pm 0.7 a	8.7 \pm 1.2 ab
15	11.6 \pm 1.0 a	6.4 \pm 1.5 b
tot	11.0 \pm 0.7 A	8.6 \pm 0.8 B

Table 3. Number (mean \pm SE) of *T. absoluta* larvae per instar preyed on by females and males of *D. errans* from 20 larvae (five per instar) for 24 hours. Means followed by different letters are significantly different (Kruskal-Wallis test, $P < 0.05$).

Larval instar	% of larvae preyed on by	
	females	males
1 st	3.4 \pm 0.5 a	2.2 \pm 0.6 a
2 nd	0.2 \pm 0.2 b	0.0 \pm 0.0 b
3 rd	0.0 \pm 0.0 b	0.0 \pm 0.0 b
4 th	0.0 \pm 0.0 b	0.0 \pm 0.0 b

Table 4

1 **Table 4.** Nymphal development time in days per instar and adult length of *Dicyphus errans* (mean ± SE) with different diets (*Ephestia kuehniella*
2 eggs, *Tuta absoluta* eggs, *Tuta absoluta* 1st instar larvae). Means followed by different letters are significantly different (Kruskal-Wallis test P <
3 0.05).

	DIET								
	<i>E. kuehniella</i> eggs			<i>T. absoluta</i> eggs			<i>T. absoluta</i> 1 st instar larvae		
instar	N	no. days	mortality	N	no. days	mortality	N	no. days	mortality
I-II	31	4.03±0.23 _a	0.0%	30	3.63±0.19 _a	0.0%	56	3.64±0.22 _a	0.0%
II-III	31	3.42±0.26 _b	0.0%	30	5.80±0.48 _a	0.0%	37	3.84±0.31 _b	33.9%
III-IV	31	6.03±0.57 _{ab}	0.0%	29	7.72±0.81 _a	3.3%	17	4.47±0.45 _b	54.1%
IV-V	29	3.76±0.23 _a	6.5%	26	4.15±0.44 _a	10.3%	6	4.17±1.19 _a	64.7%
V-A	29	3.24±0.25 _a	0.0%	25	3.52±0.34 _a	3.8%	6	2.67±0.21 _a	0.0%
tot	29	20.38±0.75 _b	6.5%	25	24.12±1.05 _a	16.7%	6	23.33±2.06 _{ab}	89.3%
female length	(mm)	4.91±0.06 _a			4.78±0.08 _a			4.85±0.05 _a	
male length	(mm)	4.72±0.08 _a			4.60±0.08 _a			4.75±0.38 _a	

Figure 1

[Click here to download high resolution image](#)

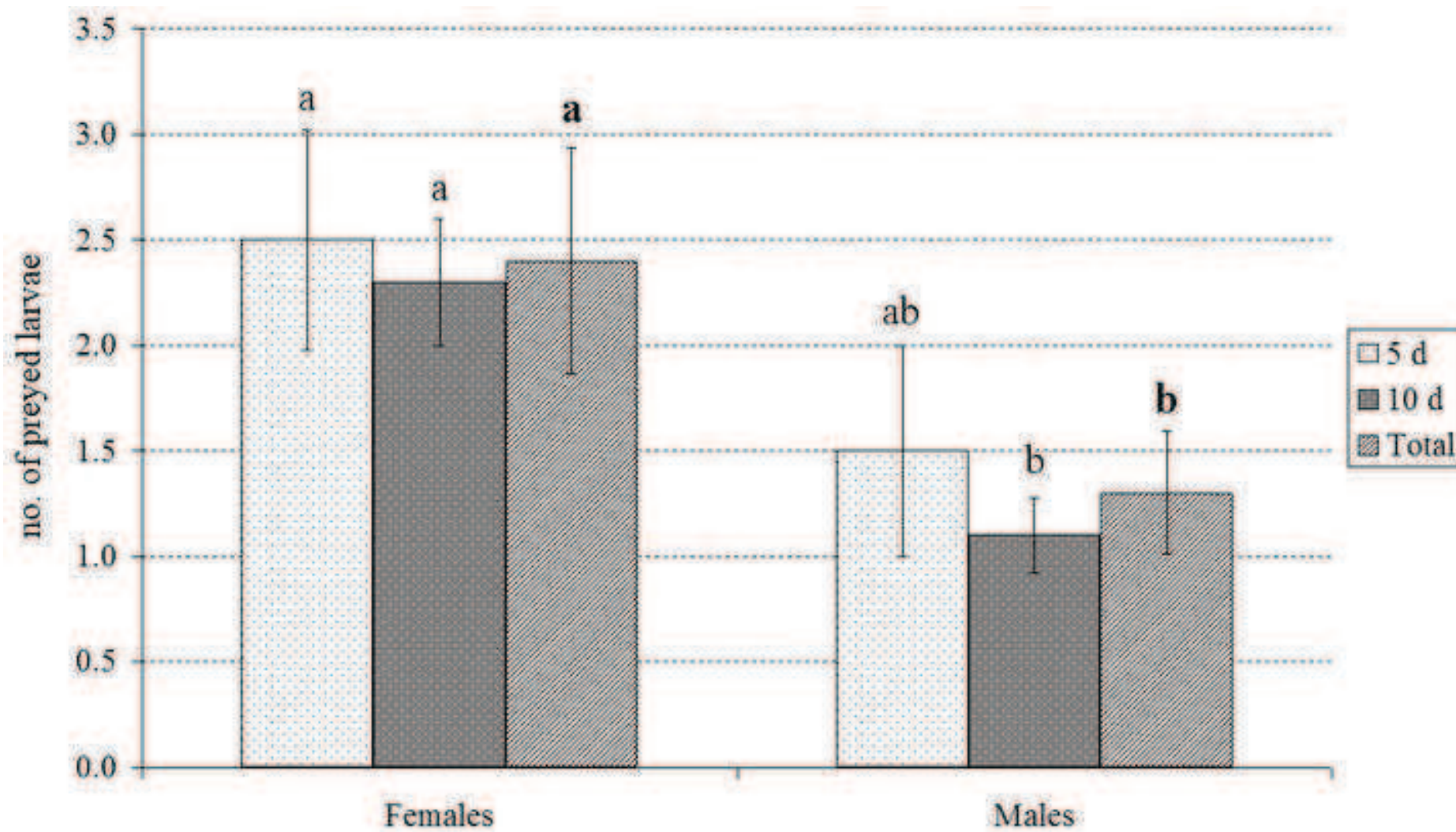


Figure 2
[Click here to download high resolution image](#)

