



## Predation and reproduction of the generalist predator *Nabis pseudoferus* preying on *Tuta absoluta*

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### Abstract

The damsel bug, *Nabis pseudoferus* Remane (Hemiptera: Namidae), is a generalist predator of small arthropods, including key insect pests of vegetable crops. In this study, we characterized the predation and development of various *N. pseudoferus* life stages when preying on the eggs and first- and fourth-instar nymphs of the invasive South American tomato pinworm, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). These findings were compared to those of the bug's common prey, cotton aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae). Of the life stages tested, females showed the highest predation rate on all tested prey, due to their high longevity, large body, and great energy requirements for reproduction. The predator's oviposition rate was clearly influenced by prey type, and was highest when feeding on fourth instars of *T. absoluta*. Considering the zoophytophagy of most of the life stages of other mirid species of tomato, and the lower propensity of *N. pseudoferus* to feed on plants, these results show that this species can be considered as a key indigenous natural enemy for sustainable pest control packages against *T. absoluta* in newly invaded areas.

### Introduction

The South American tomato pinworm, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), is a major invasive pest of tomato (Biondi et al., 2018), and also attacks other solanaceous crops and weeds (Cherif et al., 2019; Sylla et al., 2019). Since 2006, this pest has been increasingly reported in most of Europe, Africa, and Asia (Campos et al., 2017; Mansour et al., 2018; Santana et al., 2019; Han et al., 2019a,b), and it is currently threatening two major tomato producer countries, USA and China (Tabuloc et al., 2019; Verheggen & Fontus, 2019; Han et al., 2019b). In Iran, this pest was initially detected in November 2010 and then quickly invaded all provinces within just 13 months (Javadi Emamzadeh & Cheraghian, 2013; Han et al., 2019a). Soon after the arrival of *T. absoluta* in new environments, it causes economic damage to tomato crops (Desneux et al., 2011; Biondi et al., 2018).

Widespread agrochemical use has been considered as the sole curative method to control this pest. Yet, agrochemicals have clear disadvantages, such as non-target effects on beneficial organisms (Desneux et al., 2007; Biondi et al., 2012, 2015a) and the development of insecticide resistance. This phenomenon is due to the pest's short lifespan, high fecundity, and high enzymatic capacity for detoxifying insecticides (Siqueira et al., 2000; Roditakis et al., 2018; Zibae et al., 2018; Guedes et al., 2019; Silva et al., 2019). Non-chemical pest management tactics are key to the design of novel sustainable management strategies against this pest (Desneux et al., 2010; Biondi et al., 2018). Biological control is crucial for enhancing tomato's resilience against this new invasive pest.

*Tuta absoluta* is attacked both in its native area and in invaded areas by several parasitoids (Salas Gervasio et al., 2019) and predators (Zappala et al., 2013; Ferracini et al., 2019). In fact, generalist predators have a major role in suppressing *T. absoluta* populations either naturally (Miranda et al., 1998), through artificial releases (Biondi et al., 2016; Ingegno et al., 2019), or when combined with egg parasitoids (Chailleux et al., 2013) and/or selective pesticides (Passos et al., 2018; Soares et al., 2019a,b).

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Among the generalist predators that forage on tomato plants, *Nabis pseudoferus* Remane (Hemiptera: Nabidae) is a major polyphagous, Palearctic predator inhabiting crops such as alfalfa, cotton, and soybean (Braman & Yeargan, 1988; Kerzhner & Henry, 2008; Solhjoui-Fard and Sarafrazi, 2014). The prey range of *Nabis* spp. includes pests such as aphids, whiteflies, lepidopteran eggs, caterpillars, small maggots, psyllids, thrips, beetle eggs and larvae, early grasshopper instars, small spiders, and mites (Lattin, 1989; Perić et al., 2008; Cornelis & Coscarón, 2013). *Nabis pseudoferus* also helps to keep pest populations below the economic threshold (Khaghaninia et al., 2013; Solhjoui-Fard and Sarafrazi, 2014). Preliminary observations in the Mediterranean suggest that it could help control *T. absoluta*, especially in protected tomato crops (Cabello et al., 2009; Zappala et al., 2013).

Various desirable biological traits have been proposed for assessing the biocontrol efficiency of natural enemies, most importantly voracity and reproductive potential (Jervis, 2007; Coppel & Mertins, 2012). Although there have been studies on *N. pseudoferus* taxonomy and distribution (Havaskary et al., 2010; Khaghaninia et al., 2013), very little is known about the biocontrol services and the biology of *N. pseudoferus* or congeneric species which have largely been found in infested tomato plantations in Iran (Fathipour & Jafari, 2008).

In this study we describe the potential of various instars of *T. absoluta* to support the development and reproduction of *N. pseudoferus*, as well as the predator's voracity. Our findings could represent the first step toward including this predator species in integrated pest management (IPM) packages against *T. absoluta* in its newly invaded range. For comparison, we ran the same bioassays using adults of the common pest cotton aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae), as prey. This insect is highly polyphagous, found in greenhouse and field vegetables, fruit crops, and ornamentals (Blackmen & Eastop, 2000; Capinera, 2001; Yousaf et al., 2018). Its direct feeding causes leaf chlorosis and deformity, as well as sticky honeydew which provides a growth medium for sooty mold which reduces the plant's photosynthetic capacity; the aphid also transmits various plant-pathogenic viruses (Yuan & Ullman, 1996; Alford, 1999; Capinera, 2001; Pinto et al., 2008; Campolo et al., 2014). For these reasons, its control is of paramount importance and, if no efficient biological control is available, insecticides are needed (Wang et al., 2017; Ullah et al., 2019a,b; Ricupero et al., 2020).

## Materials and methods

### Study insects

The adults of *T. absoluta* used to establish a laboratory colony were collected in February 2015 from a tomato greenhouse near the city of Malayer (Hamedan Province, Iran), and established on tomato seedlings, *Solanum lycopersicum* L. cv. Super Strain B. The potted plants were kept in ventilated cages (2 × 1 × 3 m) under greenhouse conditions (25 ± 5 °C, 45–60% r.h., and natural photoperiod). To maintain the *T. absoluta* colony, 20–30 healthy and pesticide-free tomato seedlings were introduced weekly to each cage.

*Aphis gossypii* individuals were collected in May 2016 in cucumber fields in Lalejin (Hamedan, Iran) and reared on potted pesticide-free cucumber plants, *Cucumis sativus* L. cv. PS. The colony was maintained in a greenhouse under the same conditions as described above. Ten healthy cucumber plants were added each week to maintain the cotton aphid laboratory population.

Adults of *N. pseudoferus* were collected in June 2015 by net-sweeping from alfalfa research fields belonging to Bu-Ali Sina University, Dastjerd (Hamedan, Iran). Ten pairs of *N. pseudoferus* were kept in ventilated cylindrical plastic jars (11 cm high, 8 cm diameter) and provided daily with *A. gossypii* ad libitum. In addition, sterilized eggs of the Mediterranean flour moth, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae), were provided as a nutritional supplement once every 3 days. One clean, pesticide-free, healthy green bean pod was provided in each jar as an oviposition substrate and source of moisture. Green bean pods containing predator eggs were collected daily and replaced by fresh ones. The rearing containers were equipped with corrugated paper to provide predator shelters and thus to reduce cannibalistic events.

When the first-instar nymphs emerged, they were transferred to plastic Petri dishes (6 cm diameter) individually to avoid cannibalism and provided with *E. kuehniella* eggs. After adult emergence, they were divided by sex, transferred to oviposition containers in a ratio of 1:1 (five females and five males per container), and fed a mixture of cotton aphid and *E. kuehniella* eggs. All arenas were placed in the growth chamber under 25 ± 1 °C, 60 ± 10% r.h., and L16:D8 photoperiod.

### *Nabis pseudoferus* predation on *Tuta absoluta* and *Aphis gossypii*

For this assay, we used *N. pseudoferus* reared on cotton aphid and *T. absoluta* eggs and first and fourth instars for at least one generation prior to the experiments. For the experiments, we exposed to the predator those *T. absoluta* instars that spend part of their life cycle outside the leaf

mine, i.e., newly hatched first and fourth instars. Preliminary observations indicated that first and second instars of *N. pseudoferus* hardly preyed on the exposed prey instars (data not shown), thus the predation test was carried out only for nymphal stages 3–5 and adults of *N. pseudoferus*.

The experimental unit for juveniles consisted of a ventilated plastic Petri dish (9 cm diameter) and plastic cylinders (11 cm high, 8 cm diameter) for adults. One predator individual of each stage was starved for at least 4 h before being placed in the experimental units and provided with a given amount of prey. Preliminary tests for each predator instar and prey species and stage were carried out to establish the specific maximum number of prey that each predator can consume within 24 h (see Table 1). The number of killed prey was recorded daily and killed prey were renewed.

Prior to the experiments, cotton aphids and *T. absoluta* first instars were introduced into the experimental arenas to settle on tomato leaves (3 and 5 h before, respectively). To remove any bias in the oviposition pattern of *T. absoluta*, moth females were allowed to lay eggs on intact tomato leaves and then the leaves containing eggs of *T. absoluta* were excised and used in the trial.

Because the mating status can influence the predation rate, and because our preliminary observations showed that re-mating can occur in young adults of this species, the adults were always kept in couples to mimic the field scenario. Then, to estimate the female-specific predation rate, the number of prey killed by males only (obtained in a separate experiment) was subtracted from the number of prey killed in the experiment with both sexes of the predator. The number of prey killed in each treatment was recorded daily. The average daily consumed prey was estimated by dividing the total number of prey killed by the duration of each stage. The stage-specific total predation was estimated by summing the number of prey consumed during a given stage. A completely randomized design with

20 replicates per treatment was used. Control mortality was checked using 20 replicates of cotton aphid and first instars of *T. absoluta* without the presence of the predator.

#### **Nabis pseudoferus development rate and reproduction when feeding on Tuta absoluta and Aphis gossypii**

The developmental period and fecundity of females (mated) were assessed for predators feeding on eggs and first and fourth instars of *T. absoluta* and *A. gossypii*. The experimental units and design were the same as above. When adults emerged, they were coupled and after mating, male and female longevities were recorded, as well as the number of eggs produced. All experimental units were kept until the next molting at  $25 \pm 1$  °C,  $65 \pm 5\%$  r.h., and L16:D8 photoperiod. A completely randomized design with 20 replicates per treatment was used.

#### **Data analysis**

Prey mortality under predator exposure was corrected for control mortality (i.e., prey mortality due to the experimental conditions) using Abbott (1925) formula:

$$\text{corrected mortality} = \frac{(X - Y)}{X} \times 100,$$

where X and Y are the numbers of live prey in the control and treatments, respectively. The observed mortality data using fourth instars as prey did not need to be corrected, as there was no mortality in the control.

Data normality was checked with the Shapiro–Wilcoxon test, and when the normal distribution requirements of parametric tests were not met, non-parametric tests were used (e.g., the Kruskal–Wallis test). In all other cases, one-way ANOVA was used to assess the effects of predator instar, predator sex, and prey offered on the traits studied. Means were compared with Duncan's multiple range tests. For all statistical tests the level of significance was 0.05, and programs were run in SAS 2013 (SAS Institute, Cary, NC, USA).

## **Results**

### **Nabis pseudoferus predation on Tuta absoluta**

*Nabis pseudoferus* consumed eggs and early and late instars of *T. absoluta*, although the late instars less than the earlier stages (Table 2). Predation rate varied significantly in the tested stages of *N. pseudoferus* and *T. absoluta* (Table 2). The daily mean predation rate ( $F_{4,95} = 7.26$ ,  $P < 0.0001$ ) and the total predation rate ( $F_{4,95} = 11.71$ ,  $P < 0.0001$ ) of the various nymphal stages and adults of *N. pseudoferus* increased throughout the life stages, and females exhibited the highest total predation rate on *T. absoluta* eggs

**Table 1** Prey densities – number of eggs, first instars (L1), and fourth instars (L4) of *Tuta absoluta* and adults of *Aphis gossypii* – exposed to instars 3–5 (N3–N5) and adults (females and males) of *Nabis pseudoferus* in the predation assays

Predator developmental stages	<i>Tuta absoluta</i>			<i>Aphis gossypii</i>
	Egg	L1	L4	
N3	40	60	5	60
N4	60	80	7	80
N5	70	100	10	100
Male	80	130	12	130
Male + female	160	250	20	250

**Table 2** Mean ( $\pm$  SE) number of eggs, first instars (L1), and fourth instars (L4) of *Tuta absoluta* and adults of *Aphis gossypii* preyed by instars 3–5 (N3–N5) and adults (females and males) of *Nabis pseudoferus*. Mean predation is calculated by dividing the total number of prey items killed by the duration of each stage, whereas total predation is calculated by summing the number of prey consumed during a specified stage

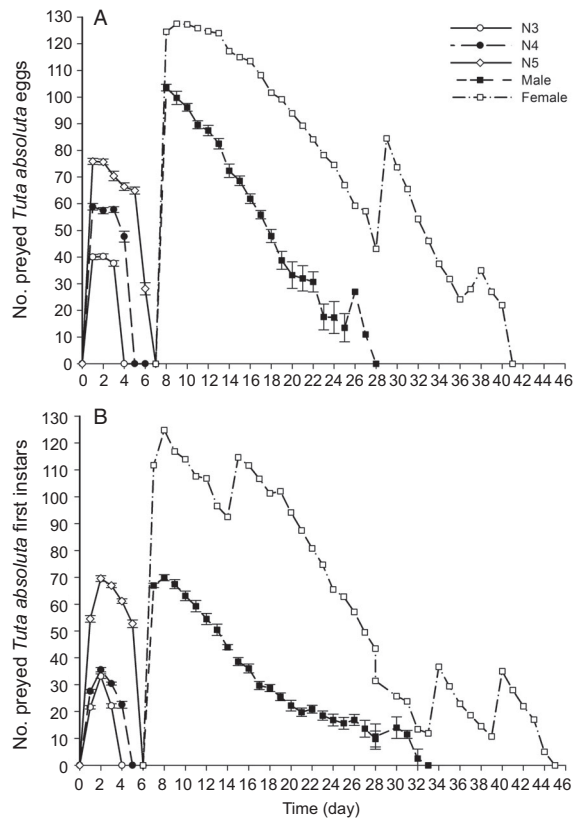
Predator stage	T. absoluta eggs		T. absoluta L1		T. absoluta L4		A. gossypii adults	
	Mean predation	Total predation	Mean predation	Total predation	Mean predation	Total predation	Mean predation	Total predation
N3	35.60 $\pm$ 1.10d	117.95 $\pm$ 1.08e	23.52 $\pm$ 0.56e	76.85 $\pm$ 1.01d	0.96 $\pm$ 0.08c	2.90 $\pm$ 0.26c	22.09 $\pm$ 0.5e	66.10 $\pm$ 0.62d
N4	51.60 $\pm$ 1.60c	221.63 $\pm$ 3.72d	27.57 $\pm$ 0.66d	116.05 $\pm$ 1.59d	1.28 $\pm$ 0.07b	3.85 $\pm$ 0.22c	35.10 $\pm$ 0.70d	106.52 $\pm$ 0.81dc
N5	61.73 $\pm$ 1.07b	381.34 $\pm$ 3.57c	59.58 $\pm$ 0.65b	304.85 $\pm$ 1.72c	1.45 $\pm$ 0.05ab	7.25 $\pm$ 0.28c	42.06 $\pm$ 0.60b	214.54 $\pm$ 0.60c
Male	70.20 $\pm$ 1.87a	982.75 $\pm$ 15.90b	37.70 $\pm$ 0.99c	749.05 $\pm$ 13.45b	1.56 $\pm$ 0.02a	34.83 $\pm$ 0.33b	39.50 $\pm$ 0.50c	745.55 $\pm$ 19.70b
Female	63.15 $\pm$ 2.61b	2510.45 $\pm$ 58.46a	62.73 $\pm$ 1.38a	2217.85 $\pm$ 49.79a	1.70 $\pm$ 0.05a	84.75 $\pm$ 4.6a	49.34 $\pm$ 1.50a	2481.91 $\pm$ 84.80a

Means within a column followed by different letters are significantly different (Duncan's multiple range tests:  $P < 0.05$ ).

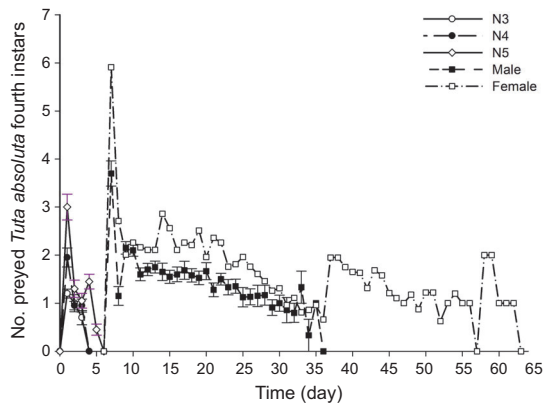
(Table 2). The predation was overall higher after insect molting and decreased to zero from the 2nd day after emergence, and male predation decreased more rapidly than female predation (Figure 1A).

The mean daily predation on *T. absoluta* first instars differed depending on the predator's life stage ( $F_{4,95} = 2.58$ ,  $P = 0.042$ ) with higher numbers for females, followed by N<sub>5</sub> and then by males (Table 2). Similarly, the total number of *T. absoluta* first instars consumed was higher for females ( $F_{4,95} = 13.01$ ,  $P < 0.0001$ ) which consumed nearly 3 $\times$  more larvae than males and 8 $\times$  more than N<sub>5</sub> (Table 2). The predation rate peaked soon after molting and then declined steeper toward the end of each life stage (Figure 1B).

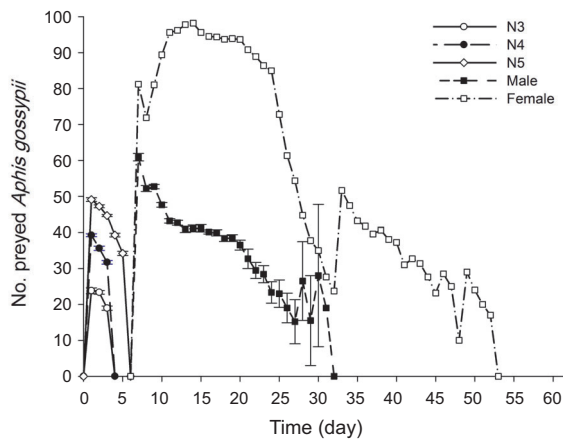
The mean daily predation rate of *N. pseudoferus* on fourth instar *T. absoluta* increased throughout the life stages ( $F_{4,95} = 4.28$ ,  $P = 0.0031$ ) (Table 2), ranging from 0.96 to 1.7 for third instars and adult females, respectively. Interestingly, no significant differences were found for males, females, and fifth instars



**Figure 1** Mean ( $\pm$  SE) daily predation over time throughout the development of *Nabis pseudoferus* nymphs (instars 3–5, N3–N5) and adults (females and males), feeding on *Tuta absoluta* (A) eggs and (B) first instars.



**Figure 2** Mean ( $\pm$  SE) daily predation over time throughout the development of *Nabis pseudoferus* nymphs (instars 3–5, N3–N5) and adults (females and males), feeding on fourth-instar *Tuta absoluta*.



**Figure 3** Mean ( $\pm$  SE) daily predation over time throughout the development of *Nabis pseudoferus* nymphs (instars 3–5, N3–N5) and adults (females and males), feeding on adult *Aphis gossypii*.

(Table 2). However, the total number consumed by an *N. pseudoferus* instar was higher for females ( $F_{4,95} = 14.8$ ,  $P < 0.0001$ ) (Table 2). As recorded for the other prey instars, the predation trend for *N. pseudoferus* nymphs and adults was higher on the 1st day of each stage tested and then decreased (Figure 2).

***Nabis pseudoferus* predation on *Aphis gossypii***

The average number of *A. gossypii* consumed daily differed among the various stages of *N. pseudoferus* ( $F_{4,95} = 5.97$ ,  $P < 0.0001$ ). The fifth instars consumed  $42.1 \pm 0.6$  aphids, which is the highest value among all nymphs and higher than the number consumed by male adults (Table 2). The total predation rate of life stages tested increased ( $F_{4,95} = 18.84$ ,  $P < 0.0001$ ); the females and third instars showed the highest and lowest values, respectively (Table 2). Unlike the daily predation rate, the total predation rate of males was significantly higher than that of fifth instars. Similar to the results obtained with *T. absoluta* as prey, feeding rate of *N. pseudoferus* on *A. gossypii* peaked on the 1st day of emergence of all stages (Figure 3).

***Nabis pseudoferus* developmental rate, longevity, and fecundity**

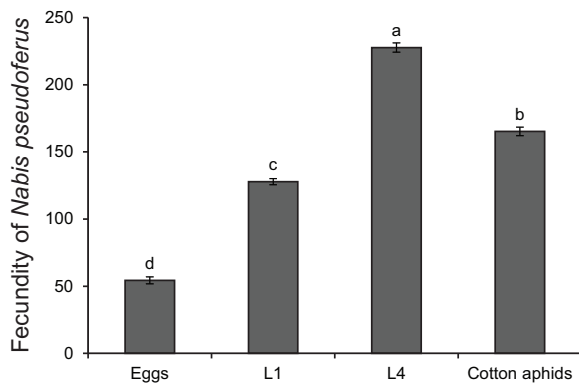
The developmental period of *N. pseudoferus* nymphs was influenced by the prey stage offered (Table 3), as third ( $H = 19.42$ ), fourth ( $H = 66.68$ ), and fifth instars ( $H = 57.85$ , all d.f. = 3,  $P < 0.001$ ). Similarly, the effect of diet influenced the longevity of females ( $F_{3,76} = 73.725$ ), mated males ( $F_{3,76} = 12.478$ ), and virgin males ( $F_{3,76} = 18.83$ , all  $P < 0.001$ ). Feeding on fourth instars of *T. absoluta* led to the highest longevity (Table 3).

Also the number of eggs laid by female predators was affected by the feeding regimes ( $F_{4,95} = 593.93$ ,  $P < 0.001$ ). The total number of eggs laid per female ranged from 54.4 to 227 when feeding on eggs and fourth instar *T. absoluta*, respectively (Figure 4).

**Table 3** Mean ( $\pm$  SE) nymphal development time (days) and adult longevity (days) of instars 3–5 (N3–N5) and adults (females and males) of *Nabis pseudoferus* preying on eggs, first instars (L1), or fourth instars (L4) of *Tuta absoluta*, or on adult *Aphis gossypii*

Predator stage	Prey			
	<i>T. absoluta</i> eggs	<i>T. absoluta</i> L1	<i>T. absoluta</i> L4	<i>A. gossypii</i> adults
N3	3.81 $\pm$ 0.12	3.31 $\pm$ 0.09	2.08 $\pm$ 0.02	2.91 $\pm$ 0.04
N4	4.35 $\pm$ 0.10a	4.18 $\pm$ 0.09a	3.02 $\pm$ 0.06b	3.07 $\pm$ 0.05b
N5	6.21 $\pm$ 0.08a	5.11 $\pm$ 0.05b	4.91 $\pm$ 0.20b	5.08 $\pm$ 0.06b
Male (virgin)	14.02 $\pm$ 0.61d	20.22 $\pm$ 0.81abc	23.58 $\pm$ 0.88a	18.91 $\pm$ 0.63bc
Male (mated)	18.65 $\pm$ 0.09c	25.05 $\pm$ 0.68b	27.37 $\pm$ 1.31a	24.53 $\pm$ 0.78ab
Female (mated)	26.05 $\pm$ 0.58d	29.72 $\pm$ 0.78c	45.30 $\pm$ 1.04a	36.50 $\pm$ 1.11b

Means within a row followed by different letters are significantly different (Duncan’s multiple range test:  $P < 0.05$ ).



**Figure 4** Mean ( $\pm$  SE) total fecundity of *Nabis pseudoferus* preying on eggs, first instars (L1), or fourth instars (L4) of *Tuta absoluta*, or on adult cotton aphids. Means capped with different letters are significantly different (Duncan's multiple range test:  $P < 0.05$ ).

## Discussion

Our results showed that *N. pseudoferus* consume significant amounts of eggs, and young and mature larvae of *T. absoluta*. These results do not concur with Desneux et al. (2010), who reported that *Nabis* sp. does not feed on eggs. In fact, our study confirmed that this predator is a voracious predator of *T. absoluta* eggs which makes *N. pseudoferus* a promising control candidate of *T. absoluta*. Egg feeding has also been shown in another study, in which third and fourth instars of *N. pseudoferus* had to choose between *T. absoluta* eggs and cotton aphids, and they preferred the eggs (Madadi & Mahdavi, 2017).

Generally, among the various predator stages tested, *N. pseudoferus* females are the most voracious, whereas the other stages are only responsible for 17% prey mortality. Because the maximum and minimum predation rates were recorded on the 1st day after molting and at the end of each life stage, respectively, it seems that the predation potential within 24 h of molting does not provide a reliable estimation of the relative predation rate. We thus propose using the stage-specific mean predation rate, which is a more comprehensive index for predation potential. In fact, our results suggest that a recently molted predator needs to compensate for nutrients lost during molting, but specific studies are needed to confirm this hypothesis. Surprisingly, the 1st-day predation rate of females was significantly lower than that of males when eggs of *T. absoluta* were offered to them. This result could be due to the higher energetic needs of newly molted females for ovarian development and thus an intrinsic preference for larger prey when naïve (Madadi & Mahdavi, 2017). Due to their greater nutritional requirements, females have a higher

predation rate than males (Mollá et al., 2014; van Lenteren et al., 2017). This again confirms that the 1st-day predation rate is not a good parameter for revealing the potential of a predator.

There is a general predation rate pattern of *N. pseudoferus* on eggs, first, and fourth instars of *T. absoluta*. Predation rate of *N. pseudoferus* nymphs and adults was highest on the 1st day of each stage and decreased slowly toward the end of each stage. However, there are some exceptions, e.g., the total predation rate of instars of *N. pseudoferus* on the fourth instars of tomato pinworm was constant throughout the stage. Indeed, it is probable that the fourth instars are too big to be consumed in significant amounts by nymphs of this predator. In addition, in the field the cryptic behavior of fourth instars reduces the predation rate of predators (Ingegno et al., 2019). The general predation rate on cotton aphid was similar to that when feeding on tomato pinworm. As when fed on eggs as prey, the 1st-day predation rate of males was significantly higher than that of females.

The voracity of a predator is key to whether it could be an efficient natural enemy against target prey (Kaçar et al., 2017; Stasek et al., 2018; Bodino et al., 2019; Ingegno et al., 2019; Wang et al., 2019). Despite studies on omnivorous zoophytophagous mirid predators of *T. absoluta* (Mollá et al., 2014), very little is known about the predation capacity of damsel bugs, especially *N. pseudoferus*. Most studies have considered the potential predation of other *Nabis* species feeding on different prey, such as leafhoppers, whiteflies, or aphids (Koss et al., 2004; Pérez-Hedo et al., 2015; Stasek et al., 2018). Fathipour & Jafari (2008), for example, found a total number of eggs produced by *Nabis capsiformis* Germar feeding on *Creontiades pallidus* Rambur of ca. 120, a number similar to the number of eggs produced by *N. pseudoferus* feeding on *T. absoluta* first instars in our study. Pena (1971) reported an average number of eggs produced by *N. capsiformis* feeding on *Bucculatrix thurberiella* Busck larvae of 112.1, also close to the number of eggs produced by *N. pseudoferus* feeding on first instar *T. absoluta*.

Several studies have investigated the suitability of life stages of *T. absoluta* as prey for other zoophytophagous mirids, e.g., *Dicyphus tamaninii* Wagner, *Dicyphus errans* (Wolff), *Nesidiocoris tenuis* (Reuter), and *Macrolophus pygmaeus* (Rambur) (Urbaneja et al., 2009; Mollá et al., 2014; Sohrabi & Hosseini, 2015; Ingegno et al., 2019). The predation rate of *N. pseudoferus* males is quite similar to values reported for *N. tenuis* and *M. pygmaeus* adults, which both consume more than 100 eggs of *T. absoluta* per day (Arnó et al., 2009) with a much higher egg predation rate than *D. errans* (Ingegno et al., 2013). The predation rate of *N. tenuis* and *M. pygmaeus* nymphs on *T. absoluta*

eggs was much lower than that of nymphs of *N. pseudoferus* (Mollá et al., 2014); however, the nymphal period of *N. pseudoferus* was longer.

A prey–predator association between *N. pseudoferus* and *T. absoluta* has been demonstrated in areas newly invaded by *T. absoluta* (Cabello et al., 2009; Zappala et al., 2013). *Nabis pseudoferus* is a polyphagous predator, known to prey on small arthropods, e.g., aphids, whiteflies, leafhoppers, and eggs and small larvae of Lepidoptera (Lattin, 1989; Triplehorn & Johnson, 2005). The advantage of using *N. pseudoferus*, instead of other predators of *T. absoluta* such as *N. tenuis*, *M. pygmaeus*, or *D. tamaninii*, would be its prevalent zoophagy, with little risk for the plants due to phytophagy (Castañé et al., 2011). Another favorable trait is the ability of *N. pseudoferus* to prey on fourth instars, whereas some mirid predators (e.g., *D. errans*) are only able to effectively kill first instars (Ingegno et al., 2013).

Our results showed that although *N. pseudoferus* can feed on all tested stages of tomato pinworm, they are not equally suitable for predator development. Among the stages tested, it seems that eggs are least suitable for *N. pseudoferus* adults, and fourth instars are most suitable, exhibiting faster juvenile development and higher longevity and fecundity. Our study represents a first step toward the integration of *N. pseudoferus* into a sustainable IPM for *T. absoluta* in tomato. Further studies are needed to understand its impact on tomato food webs (Jaworski et al., 2015; Naselli et al., 2017), field establishment and dispersal potential after artificial releases (Zappala et al., 2012; El Arnaouty et al., 2014), compatibility with chemicals (Biondi et al., 2015b; Ziaei Madbouni et al., 2017), and the true pest control ability in the field (Ferracini et al., 2019).

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