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Distribution and biological features of *Typhlodromus (Anthoseius) recki* (Acari: Phytoseiidae) on *Tetranychus urticae*, *T. evansi* (Acari: Tetranychidae) and *Aculops lycopersici* (Acari: Eriophyidae)

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Original research

ABSTRACT

The mite family Phytoseiidae contains predatory species used in biological control. However, among the 2,521 valid species, only a few are presently considered for pest management. The study focuses on a species, frequently observed in agrosystems, but whose biology is almost totally unknown: *Typhlodromus (Anthoseius) recki*. The objectives were to assess its distribution and to determine under laboratory conditions: (i) the development of three populations fed on three tomato pests (*Tetranychus urticae*, *T. evansi*, *Aculops lycopersici*), (ii) the dispersion along the tomato stem, and (iii) the dispersion from mint to infested tomato leaf discs. Based on its distribution, this species seems to be adapted to Mediterranean climate, and is preferentially found on Boraginaceae, Solanaceae, Asteraceae and Lamiaceae. Results show that *T. (A.) recki* is a generalist predator, with good performance regarding the number of prey consumed. Differences were observed between the populations considered; one population out of the three tested shows even a higher mean consumption of *T. urticae* than that recorded for *Neoseiulus californicus* and *N. cucumeris*. It is attracted by food source and is able to walk along the tomato stem. These results are encouraging enough to consider *T. (A.) recki* as a good natural enemy candidate for biological control (especially based on biodiversity conservation). Further experiments should be developed to test the predatory ability of this species at larger scale (entire tomato plants and tomato fields or greenhouses).

Keywords feeding habits; predator; biological control; tomato; distribution

Introduction

Mites of the family Phytoseiidae are predators, and some species are used for controlling pest mites and small insects, in various crops all over the world (Gerson *et al.* 2003; McMurtry *et al.* 2013). This family contains 2,521 valid species (Demite *et al.* 2020) but only a few are presently used in biological control, probably because of little knowledge on the biological features of most species. We thus hypothesise that much more species than the 20-30 species presently known for their predatory efficiency could be exploited for biological control issues (Van Lenteren 2012; Van Lenteren *et al.* 2017). Phytoseiidae mites are naturally occurring in crops and uncultivated areas (Moraes *et al.* 1986). Most Phytoseiidae species are generalist predators (McMurtry & Croft 1997; McMurtry *et al.* 2013); they feed on prey and also on pollen,

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plant exudates, sometimes plant tissues, fungi, etc. Their occurrence and diversity are strongly affected by plant phylloplane features (Karban *et al.* 1995; Kreiter *et al.* 2002; Schmidt 2004; Tixier 2018). Tomato plants have specific morphological and chemical characteristics that can act as a selective filter on Phytoseiidae communities. Trichomes on tomato leaves and stems hinder mite dispersal and development, Phytoseiidae get stuck on the sticky trichomes and die (Kennedy 2003; Simmons and Gurr 2005; Sato *et al.* 2011; Van Houten *et al.* 2013a, b). Alkaloids contained in tomato and ingested by prey adapted to this plant, can also be toxic for non-adapted predators (Koller *et al.* 2007; Ferrero *et al.* 2014a, b). However, some studies report the presence of Phytoseiidae on tomatoes (i.e. Moraes *et al.* 1986; Tixier *et al.* 2020). Studies on *Phytoseiulus longipes* Evans show that strains of this species collected on Solanaceae in Argentina and Brazil are adapted to tomato and can control both *Tetranychus urticae* (Koch) and *T. evansi* Baker & Pritchard on this crop (Furtado *et al.* 2007; Ferrero *et al.* 2014a, b). However, as *P. longipes* is endemic to the Neotropical region, the introduction of this species in Europe is confronted with regulatory and environmental problems. In a recent study, we showed that *Typhlodromus (Anthoseius) recki* Wainstein is one of the species most frequently reported on Solanaceae in Europe (Tixier *et al.* 2020). It is also observed on plants with high trichome density, or presenting spiny and sticky trichomes (especially on plants of the families Lamiaceae and Boraginaceae) (Moraes *et al.* 1986; Swirski and Amitai 1997; Tixier *et al.* 2020). Little is known on the biology of *T. (A.) recki*; it has been reported on tomatoes, feeding on mites and thrips, in Turkey and Iran (Hajizadeh *et al.* 2006; Kumral and Cobanoglu 2015a, b). In the present study, a series of experiments was carried out to characterise the feeding and dispersal habits of *T. (A.) recki*. Furthermore, its current distribution was also analysed.

Materials and methods

Distribution of *Typhlodromus (Anthoseius) recki*

Information on the geographic distribution and plant occurrence was retrieved from 59 publications (from 1958 to 2018) reporting *T. (A.) recki* occurrence (database available on request).

Plant Nomenclature

We followed the Angiosperm Phylogeny Group III's nomenclature (2009) for family, genus and species names.

Feeding habits of *Typhlodromus (Anthoseius) recki* in the laboratory

The aim was to characterise the ability of *T. (A.) recki* to feed on three prey species. Three populations of *T. (A.) recki* collected in France on Solanaceae and Lamiaceae were considered (Table 1). Two “control” species, commonly used in biological control (Knapp *et al.* 2018), both collected on Solanaceae in France (Table 1), were also studied: *Neoseiulus californicus* (McGregor) and *N. cucumeris* (Oudemans). The predatory mites were maintained in rearing units, as described by McMurtry and Scriven (1965). Pollen of *Typha* sp. was added daily as food source.

Feeding ability was assessed on three prey species: (i) *T. evansi* collected on tomato, *Solanum lycopersicum* L., in a greenhouse at Saint-Jeannet (Alpes-Maritimes, South-East France) in October 2007 and then reared in the laboratory on *Solanum nigrum* L., (ii) *T. urticae* collected in Montpellier in 2010 and maintained since then on *Phaseolus vulgaris* L. (var. Contender) in a greenhouse and (iii) *Aculops lycopersici* (Tryon) sent by Koppert BV (Netherlands) in 2017 and then reared on entire plants of *S. nigrum* in the laboratory.

Three treatments were tested: (i) *T. urticae* on bean leaf discs, (ii) *T. evansi* on *S. nigrum* leaf discs and (iii) *A. lycopersici* on *S. nigrum* leaf discs. As *T. urticae* does not develop well on

S. nigrum, it was impossible to carry out the tests on this latter plant. Three tetranychid females (*T. evansi* or *T. urticae*) were placed on a leaf disc (2.5 cm in diameter) of *S. nigrum* or *P. vulgaris* var. Contender, disposed on humid cotton in a Petri dish (10 cm in diameter) to avoid mite escape. After two days, the Tetranychidae females were removed, the number of eggs laid was counted and a predatory female (young gravid female issued from the rearing units) introduced in the experimental arena. The experimental conditions were 25 °C, 70% relative humidity and 16D: 8N photoperiod. The number of prey and predator eggs was counted each day during four days as a rapid test to screen the predator efficiency.

For *A. lycopersici* experiments, *S. nigrum* leaf discs (2.5 cm in diameter), highly infested with this pest, were placed on humid cotton in a Petri dish (10 cm in diameter). One predatory female (young gravid female issued from the rearing units) was introduced and the number of eggs laid by the predator was counted daily during four days. The experimental conditions were the same as for the Tetranychidae experiments. For each prey and predator population / species treatment, 15 replicates were performed.

Analysis of variance (ANOVA) followed by mean comparison tests (Newman-Keuls) were carried out to compare the mean daily fecundity and mean daily egg consumption of the populations / species considered for each food treatment. The analyses were performed using Statistica (Statsoft France, 2010).

Dispersal abilities of *Typhlodromus (Anthoseius) recki* in the laboratory

The experiment aims at determining “*in vitro*” conditions how *T. (A.) recki* disperses along tomato stems. The population of *T. (A.) recki* used was that collected in Saint-Guilhem-le-Désert (Hérault, South of France) on *Mentha suaveolens* Ehrhart (Table 1). This population was chosen because of its higher fecundity compared to the other strains, when fed on *A. lycopersici*. The experimental design consisted of a detached tomato stem (var. Marmande) (10 cm in length) placed in a vertical position within a box filled with agar (Figure 1). Agar was maintained moistened (wet cotton strips placed around the agar layer) to avoid mite escape and keep the leaf discs and the stem turgescient. A leaf tomato disc with pollen or *A. lycopersici* was placed at one extremity of the stem, whereas a tomato leaf disc without food was placed at the other extremity. Shelters (wool yarns and cardboard) were disposed on the leaf discs, as nests where Phytoseiidae use to lay eggs. The boxes were turned each day to avoid phototropism effects. Fifteen replicates were carried out for each treatment (pollen or *A. lycopersici*). For each replication, one young gravid female of *T. (A.) recki* (issued from rearing units) was placed in the middle of the stem. The position of the female, the number of eggs and immatures on each leaf disc was counted for seven days. Student t-tests were carried out to compare the mean number of eggs laid on leaf discs with and without food.

Assessment of the ability of *T. (A.) recki* to disperse from mint to tomato under laboratory conditions

In a recent survey, high densities of *T. (A.) recki* were observed on *M. suaveolens* (Tixier *et al.* 2020). Thus, we wondered about the use of this plant as a reservoir (banker plant) for *T. (A.)*

Table 1 Locations and plants where the populations of *T. (A.) recki*, *N. californicus* and *N. cucumeris* were collected.

Species	Locality	Geographic coordinates	Host plant
<i>Typhlodromus (Anthoseius) recki</i>	Saint Guilhem-Le-Désert, France	43°44'1.68"N, 3°32'59.46"E	<i>Mentha suaveolens</i> (Labiaceae)
<i>Typhlodromus (Anthoseius) recki</i>	Carnon, France	43°32'46.32"N, 3°58'58.8"E	<i>Datura stramonium</i> (Solanaceae)
<i>Typhlodromus (Anthoseius) recki</i>	Tarascon, France	43°48'28.03"N, 4°40'47.19"E	<i>Solanum lycopersicum</i> (Solanaceae)
<i>Neoseiulus californicus</i>	Miomo - Corsica, France	42°44'37.85"N, 9°27'39.81"E	<i>Solanum nigrum</i> (Solanaceae)
<i>Neoseiulus cucumeris</i>	Juvignac, France	43°36'50.682"N, 3°48'36.592"E	<i>Solanum boraniense</i> (Solanaceae)

Figure 1 Experimental design used to characterise the dispersal of *T. (A.) recki* along tomato stem “in vitro” conditions.

recki. This experiment aims at determining under laboratory conditions if *T. (A.) recki* would disperse from mint to tomato. The population used was the same as that considered for the stem dispersal experiment (Saint Guilhem-Le-Désert). The mint leaves were collected at Saint Guilhem-Le-Désert. Five females of *T. evansi* were deposited for three days on a tomato leaf disc (var. Marmande, 2.5 cm in diameter). The tomato leaf disc was cut into two equal parts. Each tomato half-disc was placed adjacently to a half-leaf disc of mint (same dimension as the tomato half-disc) containing two females of *T. (A.) recki*. The mint leaf discs were checked to avoid prey presence. The number of *T. evansi* (females, eggs and immatures) and the number of Phytoseiidae (females, eggs and immatures) on each half-disc were daily counted during 7 days and 15 replications were performed. Student t-tests were carried out to compare the number of *T. evansi* and *T. (A.) recki* on the two half discs through the time. A Chi2 test was carried out to compare the percentages of females, eggs and eggs+immatures on each half-disc, through the time. The analyses were performed using Statistica (Statsoft France 2010).

Results and discussion

Distribution of *Typhlodromus (Anthoseius) recki*

Typhlodromus (A.) recki is reported from 22 countries, mainly in the Southern West-Palearctic region (Figure 2) under Mediterranean climate. It is reported 421 times on 213 plant species, belonging to 138 genera and 51 families. It is recorded less than 5 times on 37 plant families, and the highest record rates were observed on six plant families (56% of reports): Asteraceae (61 reports), Lamiaceae (50 reports), Rosaceae (40 reports), Boraginaceae (36 reports), Fabaceae (26 reports) and Solanaceae (25 reports). This might suggest close relationships between this species and those plants. However, because of no close phylogenetic relationship among these plant families, such occurrence seems not related to evolutionary aspects, as also stated by Tixier (2018) and Tixier *et al.* (2020). *Typhlodromus (A.) recki* is reported less than 5 times on 123 plant genera. The highest number of reports (19% of total reports) is observed on species of the genera *Solanum* (19 reports), *Echium* (17 reports), *Vitis* (14 reports), *Prunus* (12 reports) and *Salvia* (11 reports). Again, these genera are not phylogenetically close, and *T. (A.) recki* occurrence seems not related to plant support evolution. Those data provide elements on the “probability” to retrieve *T. (A.) recki* on some plant species, although we are aware that the recorded occurrences do not exactly reflect the real distribution.

Figure 2 Map showing the present distribution of *T. (A.) recki*.

Feeding habits of *Typhlodromus (Anthoseius) recki* in the laboratory

Tetranychus urticae and bean

The average number of eggs laid over 4 days by females of *T. (A.) recki*, *N. cucumeris* and *N. californicus* was significantly different ($P = 0.0008$) (Table 2). This was due to the significantly higher fecundity of *N. californicus* (1.4 eggs/ day/ female) as no difference was observed between the three populations of *T. (A.) recki* and *N. cucumeris*. Those differences were not significant at days 1 ($P=0.07$) and 2 ($P=0.06$) but were significant at days 3 ($P<0.001$) and 4 ($P=0.001$) (Table 4, Figure 3a). For days 3 and 4, the fecundity of *N. californicus* was significantly higher than that of *N. cucumeris* and *T. (A.) recki*. Differences in fecundity through the time were only observed for *N. californicus*, a higher fecundity being observed at days 3 and 4 than at days 1 and 2 (Table 4). Even if not significant, we can note that among the *T. (A.) recki* populations, the highest daily fecundity was observed for the population collected on *Datura stramonium* L. (0.95 eggs/ day/ female) and the lowest for the population collected on *S. lycopersicum* L. (0.57 eggs/ day/ female) (Table 2).

The number of *T. urticae* eggs consumed by the populations/species was significantly different ($P = 0.02$) (Table 3). The highest mean consumption was observed for *T. (A.) recki* collected on *S. lycopersicum* (18.47 eggs consumed / day) and the lowest for *N. californicus* (10.67 eggs consumed / day) and *T. (A.) recki* collected on *M. suaveolens* (11.69 eggs consumed / day). The numbers of eggs consumed were significantly different at day 1 ($P<0.001$), day 3 ($P=0.05$) and day 4 ($P<0.001$) (Table 4). At day 1, *T. (A.) recki* from *S. lycopersicum* showed the highest consumption (40.5 eggs consumed) and *N. californicus* the lowest (6.0

N° eggs laid/female feeding on *T. urticae*

N° eggs laid/female feeding on *T. evansi*

N° eggs consumed /female feeding on *T. urticae*

N° eggs consumed /female feeding on *T. evansi*

N° eggs laid/female feeding on *A. lycopersici*

Day 1
Day 2
Day 3
Day 4

Figure 3 Cumulated number of eggs laid through the time by *T. (A.) recki* (D: collected on *Datura stramonium*, S: collected on *Solanum lycopersicum*, M: collected on *Meniha suaveolens*), *N. californicus* and *N. cucumeris* when fed with (a) *T. urticae*, (b) *T. evansi* and (e) *A. lycopersici*. Number of prey eggs consumed by *T. (A.) recki*, *N. californicus* and *N. cucumeris* when fed with (c) *T. urticae* and (d) *T. evansi*.

eggs consumed). At day 3 and 4, the highest values were observed for *N. californicus* (Table 4). Egg consumption significantly decreased from day 1 to day 4, except for *N. californicus* for which they increased (Table 4). The mean number of eggs consumed during 4 days was the highest (73.9) for *T. (A.) recki* from *S. lycopersicum*. For the other populations of *T. (A.) recki*, this consumption was about 50 eggs (Figure 3c).

There are no data on biological features of *T. (A.) recki* in literature. Differences between the three populations were observed but they were relatively low, except for the population collected on *S. lycopersicum* that consumed significantly more *T. urticae* eggs than the two others. Globally, *T. (A.) recki* has low transformation rates: many eggs of *T. urticae* need to be consumed to produce one Phytoseiidae egg (especially for the population collected on *S. lycopersicum*). These results are in accordance with biological features (observed in experimental conditions comparable to the present ones: 18 °C-25°C, 65%-75% HR and 16D:8N - 18D:6N) of other generalist Phytoseiidae species. For instance, Kasap (2010) showed for *Kampimodromus aberrans* (Oudemans), a low consumption rate (2.85 eggs / day) of *T. urticae* and a mean fecundity of one egg per day. Zemek (1993) indicated a low fecundity for *Typhlodromus (Typhlodromus) pyri* Scheuten when fed with *T. urticae* (0.72 eggs / day). Basheer *et al.* (2014) observed for *Typhlodromus (Typhlodromus) athiasae* Porath & Swirski, a daily consumption of 10 *T. urticae* eggs and a mean fecundity of 1.42 eggs/day. The consumption and oviposition rates reported in the literature for *N. californicus* are variable depending on the populations considered and the environmental conditions. Globally, the mean fecundity is about 2 eggs/female/day (Gotoh *et al.* 2004; Lebdi-Grissa *et al.* 2005; Canlas *et al.* 2006; Rhamani *et al.* 2009; Marafeli *et al.* 2014), but lower values were observed by Hatherly *et al.* (2005) (0.62 eggs/day) and Castagnoli *et al.* (2001) (1.46 eggs / day). The fecundity here observed (1.61 eggs/day) show an intermediary value; such differences might be due to strain effects (Castagnoli *et al.* 2001). Regarding *T. urticae* egg consumption, the present results (10.7 eggs consumed/ female/ day) are similar to those obtained for several strains of *N. californicus* by Castagnoli *et al.* (2001) (9.09 - 11.41) and a bit lower than the data obtained by Canlas *et al.* (2006). For *N. cucumeris*, the fecundity here observed is much lower than that reported by Al-Azzazy *et al.* (2018). The daily *T. urticae* egg consumption (14.52) is in accordance with values obtained by Li & Zhang (2016) and Zheng *et al.* (2017) and higher than those reported by Al-Azzazy *et al.* (2018).

Tetranychus evansi* on *Solanum nigrum

The number of eggs laid by the three populations of *T. (A.) recki*, *N. cucumeris* and *N. californicus* was significantly different ($P = 0.016$) (Table 2). The highest fecundity was observed for *T. (A.) recki* from *D. stramonium* L. (0.3 eggs / female/ day) and the lowest for

Table 2 Mean daily fecundity ($\pm$ standard error) of populations *T. (A.) recki* (D: collected on *Datura stramonium*, S: collected on *Solanum lycopersicum*, M: collected on *Mentha suaveolens*), *N. californicus* and *N. cucumeris* when the females are feeding on eggs of *T. urticae* (on bean leaf discs), of *T. evansi* (on *S. nigrum* leaf discs) and all stages of *A. lycopersicum* (on *S. nigrum* leaf discs).

	Daily fecundity per female Bean/ <i>T. urticae</i>			Daily fecundity per female <i>S. nigrum</i> / <i>T. evansi</i>			Daily fecundity per female <i>S. nigrum</i> / <i>A. lycopersici</i>			<i>P</i> value
<i>N. californicus</i>	1.40 $\pm$ 1.41	a	A	0.05 $\pm$ 0.22	b	C	0.83 $\pm$ 0.79	B	0.0001	
<i>N. cucumeris</i>	0.92 $\pm$ 0.76	b	A	0.18 $\pm$ 0.39	ab	B	0.89 $\pm$ 0.78	A	0.00001	
<i>T. (A.) recki</i> D	0.95 $\pm$ 0.90	b	A	0.30 $\pm$ 0.46	a	B	0.35 $\pm$ 0.49	A	0.00001	
<i>T. (A.) recki</i> S	0.57 $\pm$ 0.50	b	A	0.07 $\pm$ 0.26	ab	B	0.56 $\pm$ 0.81	A	0.00002	
<i>T. (A.) recki</i> M	0.75 $\pm$ 0.73	b	A	0.25 $\pm$ 0.52	ab	B	1.00 $\pm$ 0.81	A	0.00002	
<i>P</i> value	0.0008			0.016			0.055			

* Small different letters correspond to significant differences between the populations / species considered (Newman & Keuls, $P < 0.05$).

* Capital different letters correspond to significant differences between food sources for a same population/species (Newman & Keuls, $P < 0.05$).

Table 3 Mean daily consumption ($\pm$ standard error) of eggs of *T. urticae* (on bean leaf discs) and of *T. evansi* (on *S. nigrum* leaf discs) by females of populations *T. (A.) recki* (D: collected on *Datura stramonium*, S: collected on *Solanum lycopersicum*, M: collected on *Mentha suaveolens*), *N. californicus* and *N. cucumeris*.

	Daily consumption per female		Daily consumption per female		<i>P value</i>
	Bean/ <i>T. urticae</i>		<i>S. nigrum</i> / <i>T. evansi</i>		
<i>N. californicus</i>	10.67 ± 5.85	b	1.60 ± 1.33	b	0.0001
<i>N. cucumeris</i>	14.52 ± 10.82	ab	4.23 ± 4.30	a	0.0001
<i>T. (A.) recki</i> D	12.55 ± 9.42	b	4.52 ± 6.11	a	0.00002
<i>T. (A.) recki</i> S	18.47 ± 16.54	a	4.00 ± 3.94	a	0.00001
<i>T. (A.) recki</i> M	11.69 ± 12.23	b	3.11 ± 2.40	ab	0.0005
<i>P value</i>	0.02		0.01		

* Different letters correspond to significant differences between the populations / species considered (Newman & Keuls, $P < 0.05$).

N. californicus (0.05 eggs / female/ day) (Table 2). Significant differences were only observed at day 1 ($P=0.01$) (Table 4, figure 3b), where the highest fecundity was observed for *T. (A.) recki* from *D. stramonium* and *N. cucumeris* and the lowest for *N. californicus*. For all the species, the mean fecundity decreases through the time (Table 4). The mean number of *T. evansi* eggs consumed per day was significantly different ($P=0.01$). The highest values were observed for *T. (A.) recki* collected on *D. stramonium*, *T. (A.) recki* collected on *S. lycopersicum* and *N. cucumeris*, and the lowest for *N. californicus* (Table 3). No significant difference was observed at each day (Table 4). For all species, the daily consumption significantly decreased through the time (Table 4). The cumulated number of eggs consumed during four days ranged from 6.4 (*N. californicus*) to 18.1 (*T. [A] recki* from *D. stramonium*) (Figure 3d). These results, as in Escudero and Ferragut (2005), Moraes & McMurtry (1985) and Koller *et al.* (2007), show the low mean fecundity of *N. californicus* when fed on *T. evansi*, even lower than the values obtained in these publications (0.79 eggs/ female/ day, 0.5 eggs/ female/ day and 0.56 eggs/female/day, respectively). The low mean fecundity observed for *N. cucumeris* and the three populations of *T. (A.) recki* are in accordance with the results obtained for eight Phytoseiidae species by Moraes and McMurtry (1985). For *T. evansi* egg consumption, data in literature are scarce. Moraes and McMurtry (1986) reported a lower mean consumption by *Phytoseiulus persimilis* Athias-Henriot (1.4 - 1.7 eggs/ female/day) than the one here obtained for *N. cucumeris* and *T. (A.) recki* (3.11 - 4.52 eggs/female/day).

Aculops lycopersici* on *Solanum nigrum

The mean fecundity of the populations / species was not significantly different ($P = 0.055$) (Table 2), but we can note that the highest fecundity for *T. (A.) recki* collected on *M. suaveolens* (1.00 eggs/ female) and the lowest for *T. (A.) recki* collected on *D. stramonium* (0.35 eggs/ female). Significant differences were only significant at day 1 ($P=0.02$) (Table 4, Figure 3e). The values obtained were much lower than the ones reported for *N. cucumeris* when fed with *A. lycopersici* by Al-Azzazy *et al.* (2018) (2.12 eggs/ female/ day), for *Euseius concordis* (Chant) by Moraes and Lima (1983) (1.7 eggs/ female/ day), *Amblydromalus limonicus* Garman & McGregor (Van Houten *et al.* 2013a, b) (3.6 eggs/ female/ day) and *Amblyseius swirskii* Athias-Henriot (Momen and Abdel-Khalek 2008; Park *et al.* 2010; Van Houten *et al.* 2013a, b) (2.00, 1.7 and 2.4 eggs/ female/ day, respectively). Castagnoli *et al.* (2003) reported a decreasing rm from F1 to F3 generations (0.21 to 0.08) for *N. californicus* feeding on *A. lycopersici*. Some preliminary measurements (data not shown) indicate a consumption of 50 eriophyids mites / day by *T. (A.) recki* (population from *M. suaveolens*). This value is much higher than the one reported by Al-Azzazy *et al.* (2018) for *N. cucumeris* (consumption ranging from 12.82 to

21.69 *A. lycopersici* per day).

Considering each predator separately, *T. evansi* was the less favourable food source. However, no distinction between the populations/species was observed when the prey was *T. urticae* or *A. lycopersici*. Only, a higher fecundity was observed for *N. californicus* fed on *T. urticae* than on *A. lycopersici* (Table 2).

Dispersal abilities of *Typhlodromus (Anthoseius) recki* along tomato stem in laboratory studies

Females dispersed along the stem bridge whatever the food source (pollen or *A. lycopersici*). A low proportion was observed on the stem. They essentially moved during the first day (Figure 4). Afterwards, their movement was less frequent. The females were preferentially found on the discs with food, both for pollen and *A. lycopersici* treatments (Table 5). The number of eggs

Table 4 Mean fecundity and mean number of eggs consumed each day ($\pm$ standard error) for the populations *T. (A.) recki* (D: collected on *Datura stramonium*, S: collected on *Solanum lycopersicum*, M: collected on *Mentha suaveolens*), *N. californicus* and *N. cucumeris* when the females are feeding on eggs of *T. urticae* (on bean leaf discs), of *T. evansi* (on *S. nigrum* leaf discs) and all stages of *A. lycopersicum* (on *S. nigrum* leaf discs).

<i>Tetranychus urticae</i> on bean leaves											
Number of eggs laid											
	<i>T. (A.) recki</i> D		<i>T. (A.) recki</i> S		<i>T. (A.) recki</i> M		<i>N. californicus</i>		<i>N. cucumeris</i>		<i>P value</i>
Day 1	1.00 $\pm$ 0.81		0.60 $\pm$ 0.51		0.66 $\pm$ 0.70		0.2 $\pm$ 0.42	b	0.72 $\pm$ 0.59		0.07
Day 2	1.10 $\pm$ 0.99		0.50 $\pm$ 0.52		0.88 $\pm$ 0.60		0.8 $\pm$ 1.03	b	0.86 $\pm$ 0.83		0.06
Day 3	0.70 $\pm$ 0.82	B	0.60 $\pm$ 0.51	B	0.50 $\pm$ 0.72	B	2.2 $\pm$ 1.32	a A	1.11 $\pm$ 0.64	B	< 0.001
Day 4	1.00 $\pm$ 1.05	B	0.60 $\pm$ 0.51	B	0.88 $\pm$ 0.92	B	2.4 $\pm$ 1.35	a A	1.04 $\pm$ 0.94	B	0.001
<i>P value</i>	0.75		0.89		0.76		< 0.0001		0.06		
<i>Tetranychus urticae</i> on bean leaves											
Number of eggs consumed											
	<i>T. (A.) recki</i> D		<i>T. (A.) recki</i> S		<i>T. (A.) recki</i> M		<i>N. californicus</i>		<i>N. cucumeris</i>		<i>P value</i>
	18.60 $\pm$ 12.40	a B	40.50 $\pm$ 19.04	a A	21.77 $\pm$ 19.84	a B	6.00 $\pm$ 3.01	c C	25.31 $\pm$ 11.64	a B	< 0.001
	16.70 $\pm$ 8.12	a	12.70 $\pm$ 7.10	b	11.67 $\pm$ 8.20	ab	8.60 $\pm$ 4.27	bc	15.65 $\pm$ 8.49	b	0.08
	7.25 $\pm$ 4.71	b AB	9.20 $\pm$ 2.69	b AB	6.22 $\pm$ 2.90	b B	12.60 $\pm$ 5.54	ab A	10.15 $\pm$ 5.95	c AB	0.05
	7.60 $\pm$ 5.01	b B	11.50 $\pm$ 6.32	b AB	7.11 $\pm$ 3.65	b B	15.50 $\pm$ 5.62	a A	6.11 $\pm$ 4.11	c B	< 0.001
	0.0007		< 0.0001		0.004		< 0.0001		< 0.0001		
<i>Tetranychus evansi</i> on <i>S. nigrum</i> leaves											
Number of eggs laid											
	<i>T. (A.) recki</i> D		<i>T. (A.) recki</i> S		<i>T. (A.) recki</i> M		<i>N. californicus</i>		<i>N. cucumeris</i>		<i>P value</i>
Day 1	0.60 $\pm$ 0.51	a A	0.10 $\pm$ 0.31	AB	0.42 $\pm$ 0.78	AB	0.00 $\pm$ 0.00	B	0.60 $\pm$ 0.51	a A	0.01
Day 2	0.30 $\pm$ 0.48	b	0.20 $\pm$ 0.42		0.14 $\pm$ 0.37		0.10 $\pm$ 0.31		0.10 $\pm$ 0.31	b	0.76
Day 3	0.10 $\pm$ 0.31	b	0.00 $\pm$ 0.00		0.14 $\pm$ 0.37		0.00 $\pm$ 0.00		0.00 $\pm$ 0.00	b	0.45
Day 4	0.20 $\pm$ 0.42	b	0.00 $\pm$ 0.00		0.28 $\pm$ 0.48		0.10 $\pm$ 0.31		0.00 $\pm$ 0.00	b	0.28
<i>P value</i>	0.031		0.19		0.64		0.53		0.0002		
<i>Tetranychus evansi</i> on <i>S. nigrum</i> leaves											
Number of eggs consumed											
	<i>T. (A.) recki</i> D		<i>T. (A.) recki</i> S		<i>T. (A.) recki</i> M		<i>N. californicus</i>		<i>N. cucumeris</i>		<i>P value</i>
	9.80 $\pm$ 9.62	a	6.70 $\pm$ 5.77	a	3.14 $\pm$ 2.34		2.50 $\pm$ 1.26	a	7.80 $\pm$ 6.03	a	0.06
	3.00 $\pm$ 4.52	b	3.30 $\pm$ 3.09	b	1.57 $\pm$ 2.29		1.10 $\pm$ 1.10	b	2.70 $\pm$ 3.12	b	0.47
	2.70 $\pm$ 2.36	b	3.10 $\pm$ 2.84	b	4.28 $\pm$ 2.92		1.80 $\pm$ 1.31	ab	2.90 $\pm$ 1.91	b	0.31
	2.60 $\pm$ 1.35	b	2.90 $\pm$ 2.37	b	3.42 $\pm$ 1.51		1.00 $\pm$ 1.24	b	3.37 $\pm$ 3.02	b	0.07
	0.009		0.036		0.39		0.04		0.028		
<i>Aculops lycopersici</i> on <i>Solanum nigrum</i> leaves											
Number of eggs laid											
	<i>T. (A.) recki</i> D		<i>T. (A.) recki</i> S		<i>T. (A.) recki</i> M		<i>N. californicus</i>		<i>N. cucumeris</i>		<i>P value</i>
Day 1	0.16 $\pm$ 0.40	B	0.60 $\pm$ 0.89	AB	1.20 $\pm$ 0.91	a A	1.00 $\pm$ 0.75	AB	0.53 $\pm$ 0.57	AB	0.02
Day 2	0.25 $\pm$ 0.50		0.75 $\pm$ 0.95		1.33 $\pm$ 0.70	a	0.87 $\pm$ 0.83		1.07 $\pm$ 0.72		0.17
Day 3	1.00 $\pm$ 0.00		0.75 $\pm$ 0.95		0.88 $\pm$ 0.78	b	1.00 $\pm$ 0.75		1.29 $\pm$ 0.85		0.60
Day 4	0.50 $\pm$ 0.70		0.00 $\pm$ 0.00		0.56 $\pm$ 0.72	b	0.33 $\pm$ 0.81		0.70 $\pm$ 0.80		0.59
<i>P value</i>	0.14		0.45		0.04		0.21		0.14		

* Small different letters correspond to significant differences between days for each population/species considered (Newman & Keuls, $P < 0.05$).

* Capital different letters correspond to significant differences between the population/species for a same day (Newman & Keuls, $P < 0.05$).

Figure 4 Percentage *T. (A.) recki* females that moved along the tomato stem in the two treatments during four days (D1–D4), when the food provided was *Typha* sp. pollen or *A. lycopersici*.

laid on the leaf disc with food was significantly higher than those laid on the leaf disc without food ($P < 0.0001$ - pollen disc : 1.50 eggs/female/day, disc without pollen: 0.25 eggs/ female/day; $P = 0.03$ - disc with *A. lycopersici* : 1.09 eggs/ female/ day, disc without *A. lycopersici*: 0.40 eggs/ female/ day). No significant difference in fecundity was observed for leaf discs with *A. lycopersici* and pollen ($P = 0.13$). For a same replicate, eggs were sometimes observed on both leaf discs suggesting that the female was able to re-cross the stem bridge. Even if those results are encouraging, cut tomato stem have different physical and chemical properties than not-cut ones. Thus, further experiments on entire plants are needed to conclude on the ability *T. (A.) recki* to disperse along the stem, as shown for other Phytoseiidae species (*P. longipes* and *Phytoseiulus macropilis* (Banks)) by Sato *et al.* (2011).

Assessment of the ability of *T. (A.) recki* to move from mint to tomato leaves under laboratory conditions

One day after the beginning of the experiments, females of *T. (A.) recki* dispersed to the tomato half-disc infested with *T. evansi* (Table 6). Overall, the number of females and the percentage of occupation of each half-disc (mint vs. tomato) were not significantly different. However, at days 3 and 6, the number of females of the tomato half-disc was higher than on the mint half-disc and the percentage of females on tomato half-disc was higher than on mint at days 2,

Table 5 Position (%) of *T. (A.) recki* females and eggs on the stem and leaf discs with and without food (pollen or *A. lycopersici*).

	% of position of females		
	Leaf with food	Stem	Leaf without food
Pollen	84.2	3.5	12.3
<i>A. lycopersici</i>	59.4	13.5	27.0
	% of position of eggs		
	Leaf with food	Stem	Leaf without food
Pollen	83.3	3.3	13.3
<i>A. lycopersici</i>	84.6		15.4

Figure 5 a – Percentage of females of *T. (A.) recki* on the tomato and mint leaf half-disc through the time; b – percentage of eggs of *T. (A.) recki* on the tomato and mint leaf half-discs through the time and (c) percentage of eggs + immatures of *T. (A.) recki* on the tomato and mint leaf half-discs through the time. A star (*) indicates significant differences after Chi2 test.

3 and 6 (Figure 5).

The number of eggs+ immatures of *T. (A.) recki* was significantly greater on the mint half-disc at day 1 and day 2. At day 3, no significant difference was observed between the two treatments, whereas at days 6 and 7, the number of eggs + immatures were much greater on the tomato half-disc (Table 6). At day 7, all the eggs of *T. (A.) recki* were laid on the tomato disc.

Table 6 Mean number ($\pm$ standard error) of *T. (A.) recki* females, immatures+eggs on mint and tomato half-discs through the time and mean number of *T. evansi* females and eggs+immatures on tomato half-discs through the time.

	Number of females of <i>T. (A.) recki</i> on mint half-discs	Number of females of <i>T. (A.) recki</i> on tomato half-discs	<i>P</i> value	Number of eggs + immatures of <i>T. (A.) recki</i> on mint half-discs	Number of eggs + immatures of <i>T. (A.) recki</i> on tomato half-discs	<i>P</i> Value	Number of <i>T. evansi</i> females on tomato half-discs	Number of eggs + immatures of <i>T. evansi</i> on tomato half-discs
D1	1.33 $\pm$ 1.33	0.87 $\pm$ 0.91	0.25	0.87 $\pm$ 0.91	0.20 $\pm$ 0.56	b	3.20 $\pm$ 1.32	a
D2	0.80 $\pm$ 0.77	1.26 $\pm$ 0.79	0.14	1.47 $\pm$ 1.25	0.27 $\pm$ 0.59	b	2.26 $\pm$ 1.43	ab
D3	0.93 $\pm$ 0.96	1.06 $\pm$ 0.96	0.74	1.20 $\pm$ 1.20	0.67 $\pm$ 1.04	b	1.60 $\pm$ 1.35	b
D6	0.64 $\pm$ 0.63	1.07 $\pm$ 0.82	0.19	1.07 $\pm$ 0.99	2.07 $\pm$ 1.26	a	1.64 $\pm$ 1.15	b
D7	0.90 $\pm$ 0.70	0.63 $\pm$ 0.67	0.41	0.36 $\pm$ 0.92	1.81 $\pm$ 1.60	a	1.72 $\pm$ 1.35	b
<i>P</i> value	0.26	0.41		0.11	< 0.0001		0.007	0.32

The percentage of eggs+immatures was significantly higher on mint half-discs at day 1 and 2, whereas it was significantly higher on tomato half-discs at day 7 (Figure 5).

The number of *T. evansi* females decreased significantly through time (from 5 females / leaf disc at day 0 to 1.72 at day 7). Several hypotheses can explain this observation: (i) female escaped (but this is unlikely as they would be observed on moistened cotton), (ii) female were predated even if predation usually occur on eggs and immature stages and/or (iii) female died (but cadavers were not retrieved). The number of eggs and immatures of *T. evansi* increased until the day 3 and then decreased but no significant difference was observed through the time ($P=0.32$) (Table 6).

Conclusion

This study presents first data on the biology of *T. (A.) recki*. It confirms that this species is a generalist predator, with biological features close to those of other efficient generalist predators as *K. aberrans* and *T. (T.) pyri*. Its mean consumption of *T. urticae* is similar to *N. californicus*, which is considered as an efficient predator of spider mites (i.e. Knapp *et al.* 2018). Furthermore, it seems to perform better on *T. evansi* than the generalist species already tested. It is similarly attracted by prey and pollen, confirming its generalist statute. It is the first time that this species is tested on *A. lycopersici*, one of the most important pests in tomato crops (Trottin-Caudal *et al.* 2003; Duso *et al.* 2009). These preliminary results are encouraging considering both biological features and dispersal abilities. However, as laboratory observations do not entirely reflect real situations, trials on entire plants are required. Furthermore, because of the biological characteristics of this generalist predator, such as for *K. aberrans* and *T. (T.) pyri*, biodiversity conservation biological control should be favoured, in line with the banker plant strategy already tried in tomato greenhouses to control white flies (i.e. Frank 2010). Several characteristics of *T. (A.) recki* (endemic species of Europe, current distribution, its occurrence on Solanaceae and the fact that it is attracted by prey) constitute elements to further investigate its predation ability at plant and crop level.

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