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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 (McMurty & Croft 1997; McMurtry et al. 2013); they feed on prey and also on pollen,
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 Cобanoglu 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 turgescent. 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.) recki*.

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**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                        |
|--------------------------------|---------------------|-----------------------------|----------------------------------|
| *Typhlodromus* (Anthoseius) recki | Saint-Guilhem-Le-Désert, France | 43°44’1.68”N, 3°32’59.46”E | *Mentha suaveolens* (Labiaceae)  |
| *Typhlodromus* (Anthoseius) recki | Carnon, France      | 43°32’46.32”N, 3°58’58.8”E  | *Datura stramonium* (Solanaeaceae) |
| *Typhlodromus* (Anthoseius) recki | Tarascon, France    | 43°48’28.03”N, 4°40’47.19”E | *Solanum lycopersicum* (Solanaeaceae) |
| *Neoseiulus californicus*       | Miamo - Corsica, France | 42°44’37.85”N, 9°27’39.81”E | *Solanum nigrum* (Solanaeaceae)   |
| *Neoseiulus cucumeris*          | Juvignac, France    | 43°36’50.682”N, 3°48’36.592”E | *Solanum boranense* (Solanaeaceae) |
Figure 1  Experimental design used to characterise the dispersal of T. (A.) recki along tomato stem “in vitro” conditions.

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 adjacent 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-Paleartic 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), Lamiaeae (50 reports), Rosaceae (40 reports), Boraginaeae (36 reports), Fabaceae (26 reports) and Solanaeae (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 Solanaum (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.
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...
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 *Mentha suaveolens*), *N. californicus* and *N. cucumeris* when fed with (a) *T. urticae*, (b) *T. evansi* and (c) *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 (Gotot 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

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**Table 2** Mean daily fecundity (± 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. lycopersic (on *S. nigrum* leaf discs).

|                   | Daily fecundity per female | Daily fecundity per female | Daily fecundity per female | P value |
|-------------------|---------------------------|---------------------------|---------------------------|---------|
|                   | Bean/T. urticae S. nigrum / T. evansi | S. nigrum/A. lycopersici |                           |         |
| N. californicus   | 1.40 ± 1.41 a A          | 0.05 ± 0.22 b C          | 0.83 ± 0.79 B            | 0.0001  |
| N. cucumeris      | 0.92 ± 0.76 b A          | 0.18 ± 0.39 ab B         | 0.89 ± 0.78 A            | 0.00001 |
| T. (A.) recki D   | 0.95 ± 0.90 b A          | 0.30 ± 0.46 a B          | 0.35 ± 0.49 A            | 0.00001 |
| T. (A.) recki S   | 0.57 ± 0.50 b A          | 0.07 ± 0.26 ab B         | 0.56 ± 0.81 A            | 0.00002 |
| T. (A.) recki M   | 0.75 ± 0.73 b A          | 0.25 ± 0.52 ab B         | 1.00 ± 0.81 A            | 0.00002 |
| P 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, $P < 0.05$).
An increase in the number of eggs consumed by females of populations / species 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).

Aculus lyco persici 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 rate 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-Azzizy 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 consumed by the predators is shown in Table 4.

### Table 4 Mean fecundity and mean number of eggs consumed each day (± 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).}

|          | *T. (A.) recki* (D) | *T. (A.) recki* (S) | *T. (A.) recki* (M) | *N. californicus* | *N. cucumeris* | *P value* |
|----------|---------------------|---------------------|---------------------|-------------------|----------------|-----------|
| **Day 1**|                     |                     |                     |                   |                |           |
|          | 1.00 ± 0.81         | 0.60 ± 0.51         | 0.66 ± 0.70         | 0.2 ± 0.42        | b              | 0.72 ± 0.59 | 0.07      |
| **Day 2**|                     |                     |                     |                   |                |           |
|          | 1.10 ± 0.99         | 0.50 ± 0.52         | 0.88 ± 0.60         | 0.8 ± 0.13        | b              | 0.86 ± 0.83 | 0.06      |
| **Day 3**|                     |                     |                     |                   |                |           |
|          | 0.70 ± 0.82         | 0.60 ± 0.51         | 0.50 ± 0.72         | 2.2 ± 1.32        | a              | 1.11 ± 0.64 | b < 0.001 |
| **Day 4**|                     |                     |                     |                   |                |           |
|          | 1.00 ± 1.05         | 0.60 ± 0.51         | 0.88 ± 0.92         | 2.4 ± 1.35        | a              | 1.04 ± 0.94 | b 0.001   |
| *P value*| 0.75                | 0.89                | 0.76                | < 0.0001          | 0.06           |           |

**Table 4** Mean fecundity and mean number of eggs consumed each day (± 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).
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 $A. lycopersici$.

The percentage of females 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,

| % of position of females | Leaf with food | Stem | Leaf without food |
|--------------------------|---------------|------|-------------------|
| Pollen                   | 84.2          | 3.5  | 12.3              |
| A. lycopersici           | 59.4          | 13.5 | 27.0              |

| % of position of eggs    | Pollen        | Stem | Leaf without food |
|--------------------------|---------------|------|-------------------|
| Pollen                   | 83.3          | 3.3  | 13.3              |
| A. lycopersici           | 84.6          | 15.4 |                   |
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.

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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.
Table 6 Mean number (± 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 *T. (A.) recki* on mint half-discs | Number of females of *T. (A.) recki* on tomato half-discs | Number of eggs + immatures of *T. (A.) recki* on mint half-discs | Number of eggs + immatures of *T. (A.) recki* on tomato half-discs | P value | Number of *T. evansi* females on tomato half-discs | Number of eggs + immatures of *T. evansi* on tomato half-discs | P value |
|-------|--------------------------------------------------------|-----------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|--------|---------------------------------------------------|---------------------------------------------------------------|--------|
| D1    | 1.33 ± 1.33                                            | 0.87 ± 0.91                                               | 0.25                                                          | 0.20 ± 0.56                                                   | b      | 0.02                                             | 3.20 ± 1.32                                                   | a      |
|       | 1.33 ± 1.33                                            | 0.87 ± 0.91                                               | 0.25                                                          | 0.20 ± 0.56                                                   | b      | 0.02                                             | 3.20 ± 1.32                                                   | a      |
| D2    | 0.80 ± 0.77                                            | 1.26 ± 0.79                                               | 0.14                                                          | 1.47 ± 1.25                                                   | b      | 0.002                                            | 2.26 ± 1.43                                                   | ab     |
| D3    | 0.93 ± 0.96                                            | 1.06 ± 0.96                                               | 0.74                                                          | 1.20 ± 1.20                                                   | b      | 0.19                                             | 1.60 ± 1.35                                                   | b      |
| D4    | 0.64 ± 0.63                                            | 1.07 ± 0.82                                               | 0.19                                                          | 1.07 ± 0.99                                                   | a      | 0.03                                             | 1.64 ± 1.15                                                   | b      |
| D5    | 0.90 ± 0.70                                            | 0.63 ± 0.67                                               | 0.41                                                          | 0.36 ± 0.92                                                   | a      | 0.01                                             | 1.72 ± 1.35                                                   | b      |
|       | 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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